This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

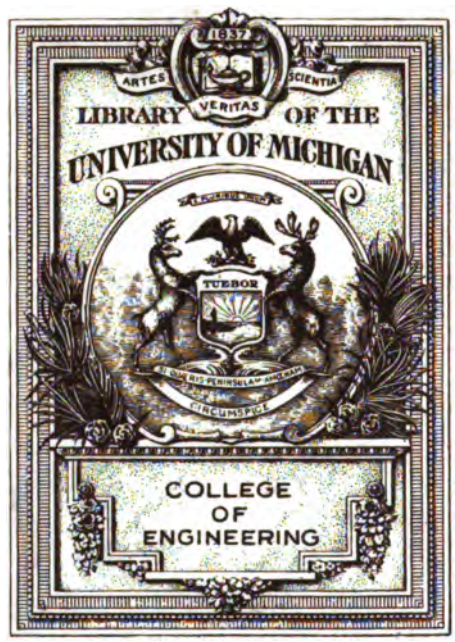
Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

B 464985

WATER RESOURCES
PRESENT *and* FUTURE USES

BY
FREDERICK HAYNES NEWELL

YALE UNIVERSITY PRESS

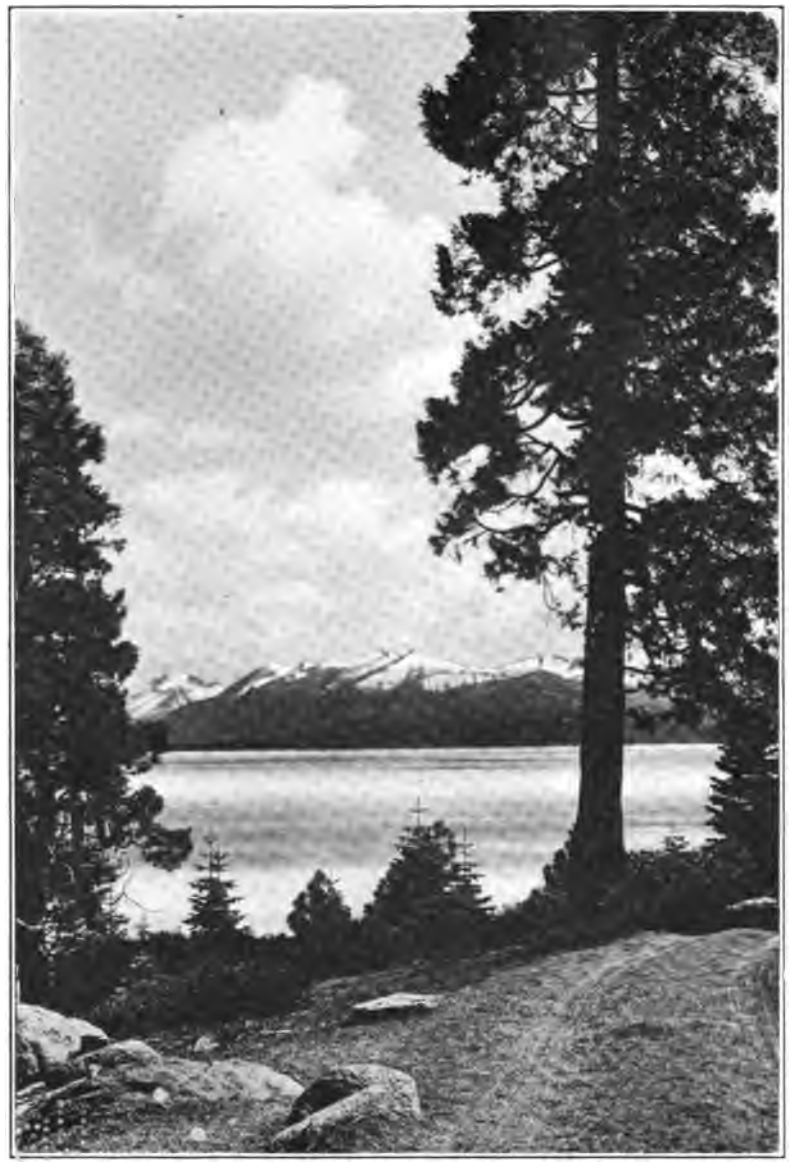

1837
ARTES
SCIENTIA
VERITAS
LIBRARY OF THE
UNIVERSITY OF MICHIGAN
TUEBOR
COLLEGE
OF
ENGINEERING

Engineering
Library
TD
345
.N54

KA
600

CHESTER S. LYMAN LECTURES

WATER RESOURCES: PRESENT AND FUTURE USES



Nature's method of conservation of water by storage. Lake Tahoe, in the Sierra Nevada on the boundary between California and Nevada, typical of the mountain lakes whose storage capacity can be increased at relatively small cost.

WATER RESOURCES

PRESENT AND FUTURE USES

BY

FREDERICK HAYNES NEWELL

PROFESSOR OF CIVIL ENGINEERING
UNIVERSITY OF ILLINOIS

A REVISION OF THE
ADDRESSES DELIVERED IN THE CHESTER S. LYMAN
LECTURE SERIES, 1913, BEFORE THE SENIOR
CLASS OF THE SHEFFIELD SCIENTIFIC SCHOOL
YALE UNIVERSITY

NEW HAVEN
YALE UNIVERSITY PRESS
LONDON · HUMPHREY MILFORD · OXFORD UNIVERSITY PRESS
MDCCCCXX

COPYRIGHT, 1920,
YALE UNIVERSITY PRESS

Reclass. 12.14 to DLK

THE CHESTER S. LYMAN LECTURESHIP FUND

The Chester S. Lyman Lectureship Fund was established in 1910 through a gift to the Board of Trustees of the Sheffield Scientific School by Chester W. Lyman, Yale College, 1882, in memory of his father, the late Professor Chester S. Lyman, for many years Professor of Physics and Astronomy in the Sheffield Scientific School. The income of this fund, according to the terms of the gift, is used for maintaining a course of lectures in the Sheffield Scientific School on the subject of Water Storage Conservation. The present volume constitutes the second of the series of memorial lectures.

It is to be noted that the lectures upon which this volume is founded were delivered in 1913, at a time when the lecturer was director of the Reclamation Service. Before the material could be completed for publication many changes took place, the world war began and the manuscript was necessarily laid aside in order to concentrate on work more or less directly connected with the war, and on the preparation of data for reconstruction studies made under the auspices of the National Research Council. On the signing of the armistice, the material was again taken up and pushed to completion, a new setting being given to it by the conditions which had developed.

367448

PREFACE

In this Day of Opportunity following the great world war, our people are calling for wise planning, for creative effort, for nation-wide coöperation, for economic administration,—all based on wider knowledge dependent upon increased study and research to furnish additional needed facts. The national wealth, present and prospective, has been mortgaged to pay the vast debts resulting from the war. We know that the burden can be lifted if we wisely employ the resources which nature has lavished but which we are so wastefully using. We must call to our aid science and scientific management,—in its true sense,—to save some of the enormous losses in fertility of the soil, in timber, in fuel, and in other natural resources, and to add to our income. The load of debt may ultimately prove a benefit to future generations, if in discharging it we learn the lessons of greater thrift and effectiveness in employing rather than in wasting our children's birthright.

Each citizen, taxpayer, and voter is concerned; upon him rest the obligations of providing the ways of discharging the war debts and at the same time of increasing the prospects of the present and future prosperity. It is to these people, to the home builders, to the plain citizens, that this message is addressed: it is hoped to interest them in the things which not only affect them immediately as breadwinners, but which give them a larger view of their opportunities. Especially is this desirable at the present, when the period of reconstruction has set in and when every thinking person is aroused to the need of his taking part in the changes going on about him. As stated by Lloyd George there is now an "opportunity for reconstruction of the industrial and economic conditions of the country such as has never been presented in the life of the world. The whole state of society is more or less molten." "There is no time to lose."

Why emphasize this particular subject of water resources or of hydro-economics? Why this rather than some other branch of science and its application? While all fields should be explored, yet if only one may be selected, there is probably no one in which larger immediate results may be obtained than in that which relates to the one mineral or substance, vital to all life and industry, and yet which because of its very common occurrence has perhaps been relatively less subject to careful study than others. While much is known, yet there is more to be discovered; while much has been done, there is probably no one substance upon whose conservation and use depends a larger share of life, health, and prosperity.

But why a general book on the subject? There are already scores of textbooks, scientific publications, reference works, and encyclopedias. There is, however, apparently no one discussion of the subject designed to present the field of conservation and use of water in connection with a consideration of the all-important question, will it pay? Will the results be worth while, not merely in money but in other substantial gains to humanity, such as better surroundings, better sanitation, or higher æsthetic values?

Do we not already have fairly complete knowledge of the facts? In some fields, yes—in others we find that in attempting the larger projects we run into the twilight zone or fog of doubts which must be cleared by the light afforded by careful, thorough research by investigation into fundamentals. It is vital under our democratic government that the ordinary citizen fully appreciate this fact and that he do his part toward stimulating research or providing means for continued extension of the bounds of human knowledge.

The apology for adding another book to the load of a weary world is to be found in the hope that in some way the plain citizen above described may be induced to look in a broad way upon these important matters and to add his favorable indorsement to the efforts of scientific men and investigators in ascertaining more definitely the facts which may be utilized by engineers and promoters in developing and utilizing the natural resources of the country for the common welfare.

ACKNOWLEDGMENT

In preparing this material, free use has been made of the assistance generously extended by many colleagues in the United States Reclamation Service, the United States Geological Survey and others in various departments of the government and in the University of Illinois. The primary inspiration for the effort is that arising from the conservation policies of Theodore Roosevelt and his associates in this work, notably, W J McGee, the student of soils and waters, and from Gifford Pinchot, the founder of the Yale Forest School, and for many years forester of the United States; also from the activities of Senator Francis G. Newlands and especially from the effective work of Geo. H. Maxwell, the executive committeeman of the National Irrigation Association. Data and description have been freely furnished by Charles E. Brooks, editor of the United States Weather Bureau; by N. H. Darton of the United States Geological Survey; and by Victor E. Shelford of the University of Illinois. Kindly assistance and advice have been had from many other conservationists and friends, notably from Arthur P. Davis, chief engineer and director, United States Reclamation Service, John C. Hoyt, hydraulic engineer, United States Geological Survey, and John C. Merriam of the National Research Council.

CONTENTS

	PAGE
Preface	7
Acknowledgment	9
Chapter I. Introduction	25
Research	26
What is Reconstruction?	27
Conservation	28
Hydro-Economics	30
Economics	31
Engineering Relations	34
Broader Relation	34
Chapter II. Water in General	36
What is Water?	36
Uses of Water	37
Where Water is Found	39
Science Involved	40
Meteorology	42
Hydrography and Hydrology	43
Geography, Geology, and Physiography	45
Biological Sciences	45
Application to Human Needs	45
Chapter III. Precipitation	47
Rainfall	47
Causes of Rainfall	49
Rainfall Measurements	52
Irregularities in Measurement	53
Periodic Fluctuation	56
Dew and Frost	59
Sky Signs	59
Forests and Mountains	60

PAGE

Chapter IV. Evaporation 65
Evaporation Measurements 69
Standard Gage 70
Results 71
Drying or Dehydration 72

Chapter V. Run-In 76
Quantity Absorbed 76
Underflow 78
Passage of Water Underground 80
Typical Underground Water Conditions . . . 81
Quantity of Water 83
Quality of Water 83
Search for Underground Water 84
Conservation of Underground Waters . . . 88

Chapter VI. Run-Off 91
Floods and Drought 95
Erosion 97
Sedimentation 99
Debris Problems 100
Varying Quantities 101
Data Available 102
Units of Water Measurement 104
Station Equipment 106
Discharge Measurements 107
Fluctuating Flow 110
Range of Fluctuation 110
Depth of Run-Off 112
Ordinary and Average Flow 112

Chapter VII. Storage of Water 117
Necessity 117
Modern Methods 119
Topography 120
Mountain Storage 121
Plains Storage 122
Surveys 122
Alternative Sites 124
Materials 125
Foundations 127
Borings 127

PAGE

Chapter VIII. Dams 130
Earth Dams 130
Core Walls 133
Paving 134
Hydraulic Dams 134
Timber Dams 136
Loose Rock Dams 136
Masonry Dams 138
Concrete Dams 138
Gates 141
Spillways 142
Retarding Dams 143
Failures 144

Chapter IX. Notable Works 148
Reclamation Service 148
Storage Works 150
Cost and Value 151
Roosevelt Reservoir 153
Pathfinder 156
Shoshone 158
Arrowrock 159
Elephant Butte 160
Lake Tahoe 161
Lahonton 163
Strawberry Valley 165
Yakima Lakes 166
Deer Flat Reservoir 166
Belle Fourche 167
Umatilla 168
Minidoka 169
Bear Lake 171
St. Mary-Milk River Systems 171
Deliveries to Reservoir 174
Underground Storage 175

Chapter X. Uses of Water 179
Costs and Benefits 179
Support of Life the First Use of Water . . . 180
Quantity Needed 182
Value of Pure Water 183

PAGE

Chapter XI. Food Production the Second Use of Water 186
Irrigation and Drainage 187
Internal Expansion 190
Diversion of Water 192
Quantity Used 194
Cost of Water 196
Economic Consideration 197
Chapter XII. Reclamation Investigations . . . 199
Financing 200
Surveys 201
Detailed Plans 205
Standard Forms 205
Construction Methods 206
Chapter XIII. Irrigation Structure and Methods . 210
Divisions of an Irrigation Project 210
Collecting Unit 210
Diversion Unit 211
Carrying Unit 212
Distributing Unit 214
Structures 215
Flumes 215
Tunnels 216
Siphons 216
Canal Lining 217
Gates 219
Automatic Spillway 219
Drops 220
Pumping 220
Chapter XIV. Operation and Maintenance . . 225
Measurement of Irrigation Water 226
Heads of Water 227
Application of Water 228
Flooding 228
Furrows 229
Subirrigation 230
Rotation of Flow 231
Duty of Water 232
Products 233
Alkali and Drainage 237

PAGE

Chapter XV. Transportation of Waste, the Third Use of Water 241

Relative Values 245
Fisheries 248
Recreational Values 248
Chicago Sewage 249
Does It Pay? 252
Water Fertilization and Self-Purification . . . 255
Needed Research 257

Chapter XVI. Industry and Transportation, Fourth and Fifth Uses of Water . . . 259

Manufacturing 259
Water Power 260
Transportation or Fifth Use of Water . . . 263
New York Canals 265
Water Storage for Canal 267

Chapter XVII. River Regulation 269

Comprehensive Projects 269
Flood Prevention or Protection 272
Misuse of Streams 274
Fishes and Their Value 275
Mussels 279
Need of Fishways 279
Frogs and Turtles 282
Birds 283
Mammals 284
Water Margins 284
Swamps 285
Aquatic Plants 287
Brackish Waters 288
Salt Water Problems 288
Coöperative Research 289

Chapter XVIII. Legal and Legislative Problems . 292

Vested Rights 292
Riparian Rights 293
Appropriation 294
Political Relations 295

PAGE

Interstate Activities 296
Federal Funds 297
Waterways Commission 299
Conclusions 301

ILLUSTRATIONS

FOLLOWING PAGE

Frontispiece

Lake Tahoe, in the Sierra Nevada, on the boundary between California and Nevada, typical of the mountain lakes whose storage capacity can be increased at relatively small cost.

Plate I 22

A. Spillway of Roosevelt Reservoir, Arizona.
B. Products resulting from irrigation of lands formerly useless.
C. Excavating a drainage ditch with drag line, Shoshone Project, Wyoming.

Plate II 32

A. Sagebrush covered desert lands, typical of millions of acres of good soil valueless for lack of water. Irrigable lands before irrigation, Yakima Valley, Washington.
B. Home and farm, typical of thousands made possible by conservation of water by storage, Minidoka Project, Idaho.
C. Floods restrained by the Roosevelt Reservoir, Arizona, water otherwise destructive held in part for future use in generation of electric power and for irrigation of arid lands, illustrating double or triple benefits of conservation.
D. Granite Reef diversion dam on Salt River, Arizona.

Plate III 70

A. Tower of United States Weather Bureau, carrying evaporation pans, near Salton Sea, California.
B. Towers in Salton Sea, California, supporting evaporation pans.
C. Standard Evaporation Station, United States Weather Bureau.

Plate IV 90

A. Small earth reservoirs or tanks for storage of water pumped by windmills from so-called underflow, Garden City, Kansas.
B. Storage in mountains. Jackson Lake at head of Snake River, Idaho-Wyoming.
C. Brush wing dams to prevent erosion of levees, near Yuma, Arizona.
D. Sedimentation, adding silt to clear water for the purpose of reducing seepage from a canal, Minidoka Project, Idaho.

FOLLOWING PAGE

Plate V 106

A. Measuring flow of water in Ironstone Canal, near Montrose, Colorado.
B. Weir for measuring water in one of the canals of the Williston Project, North Dakota.
C. A plains reservoir site, that utilized for the Cold Springs Reservoir of the Umatilla Project, Oregon.
D. A reservoir built on the plains or open valley lands, because of lack of adequate natural storage sites in the mountains. Deer Flat Reservoir, Boise Project, Idaho.

Plate VI 126

A. An unusually good dam site in a narrow granite gorge with bedrock a few feet below the surface. Site of the Pathfinder Dam on North Platte River, Wyoming.
B. Deceptive appearance of foundations, river apparently flowing upon bedrock, but diamond drill shows that the channel is filled with bowlders and loose rock to a depth of sixty feet or more. Site of Shoshone Dam, Wyoming.
C. Site of Roosevelt Dam, Arizona. Showing highly inclined strata of side walls and narrow gorge.
D. Building a dam of earth, showing core wall in center with earth banks above and below, to be widened until they join, covering the core wall; test pits on hillside in line of core wall; Strawberry Valley Dam, Utah, looking upstream.

Plate VII 134

A. Earth dam built by hydraulic process, washing the earth and loose rock from the hillside and sluicing the debris out to the site of the dam. Conconully Reservoir.
B. Earth dam built by hydraulic process; spillway at left in recent rock excavation. Conconully Dam, Okanogan Project, Washington.
C. Paving on water side of earth dam, Belle Fourche Project, South Dakota.
D. Concrete storage dam, at East Park, Orland Project, California.

Plate VIII 142

A. One of several rows of sluice gates to control water flowing through the Arrowrock Dam, Boise Project, Idaho.
B. Operating cylinders for sluice gates, also portion of inspection galley in Arrowrock Dam, Boise Project, Idaho.
C. A series of curved spillway sections near East Park Dam, Orland Project, California.
D. Erosion at lower toe of Mexican diversion dam on Rio Grande above El Paso, Texas.

FOLLOWING PAGE

Plate IX 150

A. Sheep grazing along canal in vicinity of Huntley, Montana, illustrating how they may be used to keep down the weeds on canal banks.
B. Tunnel for diversion of North Platte River at Pathfinder Dam, Wyoming.
C. Shoshone Dam, Wyoming, as seen from water side before completion.
D. Part of reservoir created by Shoshone Dam, Wyoming, with wagon road around side of reservoir leading to Yellowstone National Park.

Plate X 160

A. Arrowrock Dam, Boise Project, Idaho, water issuing from five openings in the upper row.
B. Elephant Butte Dam, New Mexico, under construction.
C. Earth dam on Carson River, Nevada.
D. Lake Keechelus, Washington, one of three large lakes converted into reservoirs at head of Yakima River. Temporary wooded crib dam above site of permanent earth dam.

Plate XI 178

A. Dam at head of Sunnyside Canal, Washington, diverting water which comes from storage at the head of Yakima River.
B. Lower embankment of Deer Flat Reservoir, Boise Project, Idaho.
C. Laying concrete blocks on upper face of Owl Creek Dam, Belle Fourche Project, South Dakota.
D. Cold Springs Dam and outlet tower, Umatilla Project, Oregon.

Plate XII 186

A. Main feed canal, concrete-lined section, for carrying flood water to Cold Springs Reservoir, Umatilla Project, Oregon.
B. Spillway of the Minidoka Dam, Idaho, with power house in distance.
C. Cement-lined canal carrying the water of Truckee River to Carson Reservoir, Nevada.
D. Flume delivering water of Truckee River into Carson Reservoir, Nevada.

Plate XIII 198

A. Underground storage of water in the Great Plains area. Pumping from the so-called underflow near Garden City, Kansas.
B. Building canal by wheeled scraper, Boise Project, Idaho.
C. Desert land before irrigation, Shoshone Project, Wyoming.
D. Alfalfa and hogs, profitable products of the arid region. Sun River Project, Montana.

FOLLOWING PAGE

Plate XIV 214

A. Whalen diversion dam of North Platte Project, Nebraska-Wyoming.
B. A lined tunnel with approach to canal. Grand Valley Project, Colorado, capacity 1,425 second-feet.
C. Farm lateral delivering water to furrows, using canvas dam, Shoshone Project, Wyoming.
D. Using water, stored by Roosevelt Reservoir, for irrigation of young orange grove, applying it by furrows. Salt River Valley, Arizona.

Plate XV 232

A. Cement flume, Tieton Canal, Washington.
B. Casting portions of reinforced concrete cement flume, Tieton Canal, Washington.
C. Siphon conveying waters of Interstate Canal under Rawhide Creek, North Platte Project, Nebraska.
D. Cylindrical gates in Franklin Canal, El Paso, Texas.

Plate XVI 240

A. Measuring water to farm laterals. Uncompahgre Project, Colorado.
B. Stacking alfalfa hay, Garden City Project, Kansas.
C. Alfalfa field injured by alkali due to excessive irrigation, Shoshone Project, Wyoming.
D. Apple orchard, North Yakima, Washington.

Plate XVII 258

A. Blackfeet Indians on their reservation in Montana employed on conservation works.
B. Apache Indian laborers at Roosevelt Reservoir in Arizona.
C. Mountain forests and lake made possible by the run-off from the forested area.
D. Underground storage made available by deep boring; an artesian well, New Roswell, New Mexico.

Plate XVIII 268

A. Furrow irrigation, Yakima Project, Washington.
B. Farm lands destroyed by floods; banks of New River near Imperial, California.
C. Increased length of spillway produced by rectangular bays, Klamath Project, Oregon.
D. River gates in Minidoka Dam, Idaho.

FIGURES

PAGE

Fig. 1. Sections illustrating conditions which control formation of flowing wells or of springs 82

Fig. 2. Profile showing factors indicating depth to water-bearing stratum at a given locality 86

Fig. 3. Apparatus illustrating loss of head or hydraulic grade due to leakage 87

Fig. 4. Profile indicating conditions of success or failure of artesian wells 87

Fig. 5. Comparison of height of Roosevelt Dam with Capitol at Washington, District of Columbia 147

Plate I. A.

Man's method of conservation. Portion of Roosevelt Reservoir, Arizona. A dry valley made into a lake.

Plate I. B.

Products resulting from irrigation of lands formerly useless. The stack shown above contains 75 tons of alfalfa hay from 16 acres on Minidoka Project, Idaho; the stack is 50 feet long, 38 feet wide, and 35 feet high.

Plate I. C.

Excavating a drainage ditch with drag-line, Shoshone Project, Wyoming.

WATER RESOURCES: PRESENT AND FUTURE USES

CHAPTER I

INTRODUCTION

Reconstruction of things, of men, and especially of ideals was the inevitable demand as soon as the world awoke to the magnitude of the destruction being wrought by the great war. As hostilities spread and more and more peoples were drawn in, with ever widening ruin to property and institutions, the need for devising far-reaching plans for rebuilding became more pressing. While every possible effort was being made to quickly win the war, yet, at the same time, certain far-seeing men recognized that if peace came without having adequate plans for reconstruction, much of the fruit of victory would be lost. Thus it was that many of the nations, even during the height of the war, created organizations such as the British Ministry of Reconstruction, whose duty it was to prepare plans and especially to conduct researches into those matters which with the reëstablishment of peace would have prime importance.

Many a statesman of Europe and each propagandist the world over has seen the present opportunity and need. He has had his vision of what may be accomplished at the moment in the world's history when so much that is old and bad has been weakened and so much that is idealistic may become real if only this golden opportunity is grasped. The towns of the war zone, with their unsanitary surroundings, their narrow, crooked streets, wrecked by war, may be rebuilt with straight, broad avenues and modern improvements. Likewise, some of the ancient institutions with cramping influence upon industry, education and government in every country, now that their foundations are shaken, must be rebuilt from the ground up and may be planned to better meet the needs of present and successive generations.

An incursion into the fields of opportunity and need shows that there is an almost infinite variety of tasks which should be undertaken. The number and magnitude of these are appalling. Wonder is felt that with the achievement of our present civilization we should have left undone so many of these tasks. They pertain to every department of human life and involve the health, industry, and prosperity of nations as well as of individuals. One great group of problems includes labor; another, the vital questions of food and its greater production; another, the transportation methods on land and on sea and so on through the whole range of human interests.

Among all these groups of things to be done there is one which has a peculiar appeal to the ordinary citizen because so close to his daily life. Yet because so familiar it is often overlooked, while attention is drawn to more remote happenings. This is the group of questions mainly in the physical and biological sciences which in the decade preceding the world war were discussed under the then popular name of "conservation."

Reconstruction, as the word is now generally used, covers much the same group of questions, together with newer ideals and aspirations, and implies a better utilization for the common welfare of the natural resources and the more effective employment of physical and moral forces. It, however, in popular use, seems to involve more of the conception of utility, of practical and immediate application to the problems confronting us.

Research. It is now apparent—as never before—that research must precede effective work in reconstruction or in conservation. This fact, while generally known during the discussion of conservation problems, has been emphasized by the needs created by the great war. It is seen more widely than in the previous decade that to clear the line of progress there must be a larger, more systematic and more vigorous study into things as they are in order to eliminate points of uncertainty.

Many things whose lasting qualities have been assumed have failed in part under the shock of war. Others formerly regarded as dubious have made good. We must utilize the facts now at hand and while we cannot wait for all of the results of laborious and time-consuming research, yet we are not justified in abating

any of our energies in initiating and bringing to useful conclusions the lines of investigation where further facts are needed.

America, as compared with her resources and needs, has been remiss in research. While inventive genius, especially in mechanical lines, has been encouraged, research as such has been left largely to other nations. Recognizing this condition, our reconstruction ideals should involve larger and better planned instrumentalities for research. We should quickly test what is known and explore in directions where additional knowledge is needed. But before outlining these attempts it is wise to try to define what is meant by reconstruction, by conservation, by research and by some of the other commonly used terms.

WHAT IS RECONSTRUCTION? This word like many another in popular use has almost as many meanings as there are persons employing it. To the medical man it means the rebuilding of health and physical strength; the injured soldier is to be rehabilitated to return to the ranks, or to be prepared for self-support in civil life. To the army engineer reconstruction means the rebuilding of roads, railroads, bridges and towns; the restoration of devastated country. To the citizen and business man reconstruction means getting back to normal conditions. To the propagandist it means the opportunity to put into practice the improvements which in his opinion are vital to the progress of the race. As a somewhat conservative definition the following may be offered:

Reconstruction is the rebuilding on normal peace lines of the activities, mental and physical, which prevailed before the war, with such improvement or advance in ideals, methods and machinery as may have been made possible by recent experience. It begins primarily with the returning soldier, in his rehabilitation if necessary, and his return to the industry which best suits his capacities and desires. It includes the placing of other war workers as conditions change and of any human effort where it may be most effective. It means better use of our natural resources in lands, minerals, waters, and forests, to furnish larger and more nearly equal opportunities for each citizen and the placing of industry, including agriculture, mining and transportation, on a basis to meet the changed needs of the country.

In short, it means the intelligent planning and execution of plans for a better community.

On grouping these reconstruction problems and assembling them in logical order, it is seen that there is behind each an unsolved or partly solved question in some one of the physical or biological sciences whose application in engineering, agriculture or other useful arts is fundamental in the public welfare. Here additional careful research is required. For example, for better food production there are required answers to questions regarding soil, climate and waters. Behind transportation are certain geographical and other limitations affecting largely inland navigation. Behind health, among others, are such questions as better water supply and prevention of water-borne diseases.

In short, in our study of reconstruction problems, if we go back to the fundamentals of health, prosperity, and comfort of individuals and of the nation, we find that as a significant factor there stands prominent and more complete knowledge of some one simple substance whose occurrence and use demand a larger survey accompanied by comprehensive projects of research and development of effective means of utilizing the scientific and technical knowledge thus gained.

Conservation. As part of any reconstruction program there must be included conservation. This word so popularly used since 1902 has become almost hackneyed. It is now replaced or merged in the more inclusive and perhaps more utilitarian term, reconstruction, yet the ideal still remains, and men who were most ardent conservationists have turned their zeal and energy to the solution of the problems which have become acute because of conditions following the world war.

During the progress of the war the principles of conservation were exploited and immediately put into practice on a scale and with a thoroughness hardly dreamed of by the most ardent advocate of conservation in the years gone by. The whole nation willingly adopted extreme measures which even the most visionary conservationist had hardly expected to see attempted even on a modest scale. The methods tentatively discussed in earlier years to conserve and better utilize coal, oil, and other

fuels, food and forage were extensively practiced. Consideration was given to ways and means of securing still greater economies; forces were set in motion which it is hoped will bring about the realization of the dreams of enthusiasts with reference to conservation of other natural resources such as water powers, and on a scale previously unknown.

Conservation, and to a large part reconstruction, at the bottom is good housekeeping. It involves the idea of thrift and of good business management. The present age differs from those which have gone before in the appreciation of the need of careful and scientific study of natural resources, in the weighing of costs and benefits in utilizing these, viz., in the economics of their use. The time has passed when the well-informed man boasts of the unlimited resources of the country; it is no longer considered a mark of progress to permit the great coal beds to be carelessly mined, the forests to be freely burned and the rivers to be neglected. The study of the management of the affairs of the government and of the community with reference to the sources of income, expenditures and development of the natural resources has come to be appreciated as never before.

It has been a characteristic American trait to expatiate upon the natural resources of our country. The vastness of the area and of the mineral wealth appeals to the imagination. It seems to reflect glory upon all who are so fortunate as to be in such a great land. Unconsciously we take credit to ourselves for these resources as though the fact that we are living here attests our superiority over the rest of the world. It would be more fitting, however, instead of dwelling upon our own superior merit in being in such a country, for us to feel that these resources impose a corresponding obligation and a duty to utilize them in the best way for the welfare of mankind. The tendency has been, however, to accept these wonderful opportunities as a gift to individuals and to permit the stronger or shrewder man to exploit them for private gain rather than for the strengthening of the nation. The unspoken thought has often been that whatever is good for me should be good for the community, and that my personal success and that of my friends measure the highest achievements.

The public-spirited men who have held to the opposite views, namely, that the great natural resources such as mineral wealth and water power are a public trust to be administered for the greater good to the greatest number, can hardly hope to attain immediate popularity; while the greatest number accept this as a matter of course, the active aggressive minority, whose plans for personal gain may be interfered with, are ever active in their opposition to the men whom they characterize as "visionary and impracticable" in their altruistic ideals. Nevertheless, with the spread of reconstruction demands these ideals are being realized in part; we have reason to be greatly encouraged when we look back over the history of the past ten years and see the awakening of the public conscience and the support which has been given to the plans of conservation.

Now, as never before, it is being appreciated that a nation like an individual cannot be rich without proper economy and that in public affairs, as in private, the rules of thrift, of good housekeeping, of good business management, must be observed. As striking examples of the need and benefit of such national thrift may be cited the dormant or partly used opportunities in water powers and related forces.

Hydro-Economics. Considering all of the substances or natural resources which have to do with health, comfort and prosperity, there is no one which approaches in importance the most common of all our minerals, and the only one vital to life, namely, water. Water is so common, its use is so intimately associated with every necessity and comfort that like most common things its importance is overlooked. It is at the foundation not merely of life itself but of every industry, and upon its control and best use depend the health and prosperity of the human race. If, therefore, in our reconstruction program we start with this single fundamental we are at once confronted by a group of problems all dependent for their solution upon a more complete knowledge not merely of water and the water resources of the country but of the laws of nature which govern the occurrence and use of water as a material means of satisfying human needs.

More than this we must be prepared to apply this knowledge

in an efficient manner. We should be able to show that the results will be worth more than they cost, though these returns may not be in money values but in better health or in ways which make for a higher civilization.

To cover these two conceptions a new term is necessary or at least one which has not been in common use. For this purpose the word "hydro-economics" is perhaps most suitable in that the prefix conveys the idea of water and is followed by the conception of its efficient employment, of utility or of thrift.

But what has hydro-economics to do with reconstruction or with conservation? A little consideration will show that the substance, water, is the one mineral which as above noted is necessary for all life. It enters into most of the far-reaching plans for the rebuilding or development of the nation's resources in men, materials or industries. No activity of reconstruction nor even of existence, can take place without water. It is a prerequisite in all far-reaching projects.

Often this prerequisite is not definitely recognized simply because we infer that as a matter of course water exists in proper quantity or quality. It goes without saying that the reconstruction of the wounded soldier can only take place under the assumption that he is provided with the proper quantity and quality of water for drinking, cooking, bathing, laundry and other purposes. It is not necessary to discuss this elementary fact in such connection. In other lines of reconstruction such, for example, as the utilization of desert or waste lands, the question of water supply is the one large item to be given consideration. Between these two extremes the question of water and its use may be found to be involved more or less directly in every reconstruction problem.

Economics. According to the definition in the dictionary this is the "science that investigates the conditions and laws affecting the production, distribution and consumption of wealth or the material means of satisfying human desires." Or to put the matter in more homely form, it is the consideration of the reply demanded from every promoter or propagandist, "Will it pay?"

Each scheme or project of conservation or of reconstruction

or in fact any undertaking must respond to the inquiry, "Will the result—whether material or moral—justify the outlay?" The man of affairs puts the question bluntly in the current vernacular, "What are the profits?" The scholar reaches the same end by asking as to whether it will be economically advantageous.

Among the almost innumerable plans for promoting future prosperity choice must be made of those which are most likely to pay. The return or reward may not necessarily be in money value. In fact, the question as to whether any one line of effort will pay best must be considered not in immediate financial terms but in the less tangible and more far-reaching result of attainment of the ideals of a people.

The combination of the two words hydro and economics may be narrowly defined as the economics of water supply or more broadly stated as a consideration of the question as to whether it will pay to utilize or develop the natural resources in water in connection with one or another of the problems of reconstruction.

Many of the questions which might be asked in hydro-economics may be answered as soon as they are stated. To take an extreme case, no one would hesitate to assert that any obtainable amount of money may be used in procuring an adequate amount of water for drinking, cooking and other purposes needed in the rehabilitation of our soldiers. At the other extreme is the question of state or even national importance—Is it possible and will it pay to try to procure an adequate supply of water to develop certain industries or to irrigate certain desert lands? That it will pay and that the results in many cases are well worth the expenditure has fortunately been demonstrated by extensive works already completed by the national government.

Comfortable homes dotting the valleys and diversified industries located at centers of population in a formerly desert country testify to the practical results of trying out one of the numerous forms of hydro-economics, viz., that of water conservation by storage. For several years prior to the outbreak of the world war each season showed progress in added

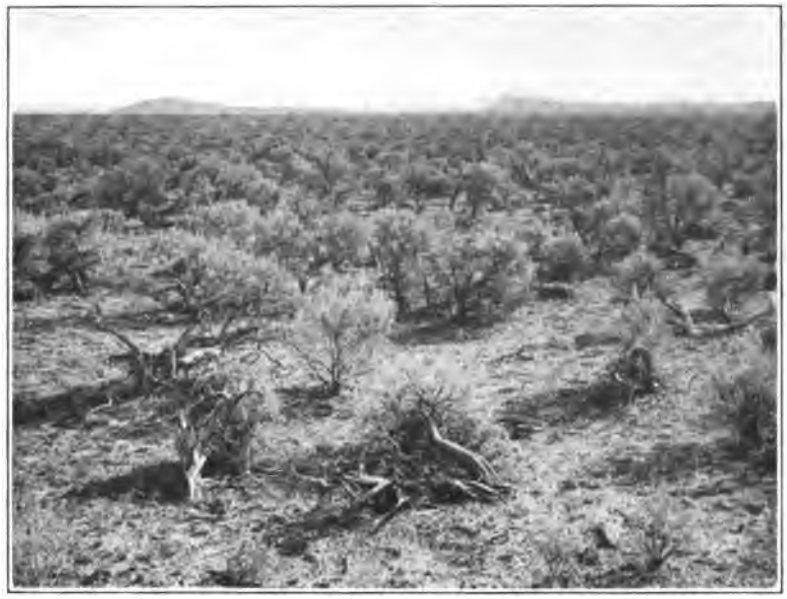


Plate II. A.

Sagebrush covered desert lands, typical of millions of acres of good soil valueless for lack of water. Irrigable lands before irrigation, Yakima Valley, Washington.

Plate II. B.

Home and farm, typical of thousands made possible by conservation of water by storage, Minidoka Project, Idaho.

Plate II. C.

Floods restrained by the Roosevelt Reservoir, Arizona, water otherwise destructive held in part for future use in generation of electric power and for irrigation of arid lands, illustrating double or triple benefits of conservation.

Plate II. D.

Granite Reef diversion dam on Salt River, Arizona.

works both great and small. Many projects for conservation of water were then being planned or built, putting into visible form an appreciation on the part of the public of the opportunities to be enjoyed. The period from 1904 to 1914 was particularly rich in results, the most notable among these being the achievements of the United States Reclamation Service in the construction of large reservoirs at the head waters (see Pl. I. A) or along the streams issuing from the mountains of the arid west.

Some of the largest and highest dams in the world for holding flood waters were then built. At the time of the entrance of the United States into the war these works were adding to the food supply and material prosperity of the country through the large crops produced from lands which without this supply would have remained desert. The contrast between the naturally unproductive and valueless conditions and the highly productive state to which these lands have been brought is shown by Pls. II. A and B, the change shown in the latter being wrought by water conservation in reservoirs created by these great dams.

The success attained by the application of the principles of hydro-economics or of water conservation in the western part of the United States prior to the war had begun to stimulate interest in similar undertakings throughout the remainder of the country and of the world in general. Prominent engineers from nearly every civilized land had come to see these reclamation projects and to study the methods of laying out the works, of handling materials, of organizing the working force and particularly of solving the related economic and social problems.

The application of the principles of water conservation also had a secondary but highly important influence in stimulating studies directed toward increased efficiency in related work; the efforts in this one direction assisted in obtaining higher economy in other undertakings. There was thus put into practice in several branches of the federal government a higher degree of efficiency than had hitherto prevailed. This was manifest particularly in the direction of cost keeping, in making purchases and in laying out works. It may not be too much to claim that

the success attained by the employees of the government in the practical application of conservation principles in reclamation and in forestation did much to strengthen public confidence in the efficiency of the government in undertaking larger problems connected with the operations of the world war.

Engineering Relations. In attacking the reconstruction problems which directly or indirectly involve the study of hydro-economics, it is necessary to explore far back into the fundamentals of many of the mathematical, physical and biological sciences. In their application in solving these problems engineering knowledge and skill are involved. In fact, the engineer has the principal responsibility. As a man of ingenuity and of vision he must see the entire field and initiate the work. Later he must call in the agriculturist and seek aid and advice from the business man and economist. In fact, for success he must supplement his skill by wide business experience and be able to form correct opinions as to whether any given undertaking apparently necessary and practical will be worth the cost.

Historically the original hydro-economists or conservationists were the engineers whose names and nationalities are unknown, but who during remote antiquity built in Egypt, Mesopotamia, India and China the structures little and big for the irrigation or drainage of lands otherwise unproductive. In this sense reclamation may be said to antedate civilization. Conservation, or reconstruction as we may now term it, utilized not merely the natural substances and forces, but turned to higher uses and efforts of the human race, elevating individuals and nations from slavish dependence upon the fluctuation of water supply to a status where each year they could produce ample food and secure the comforts coming from assured and bountiful crops.

Broader Relation. Nor has this conservation of human energies been wholly a matter of past generations. One of the incidents of modern engineering and the application of its principles in reclamation of the desert lands is that of the development of the neglected or little considered natives of the United States and of other countries where water conservation has been wisely practiced. The improved conditions, for example, in

India and Egypt, through the work of the British engineer, are well known. In the United States a similar though less extensive result has been obtained in providing needed water supply for some of the American Indian tribes or "Amarinds," and in permitting them to practice better agriculture than was ever before feasible. The immediate and direct result is the improvement of the Indian laborer. The opportunities offered at the remote places where he lives and where storage reservoirs are being built have lifted him in the scale of civilization and have made possible the use of his time which otherwise would have been wasted. This condition is typified by Pl. XVII. A, which shows some of the members of the Blackfeet Indian tribe working on the canals and embankments on their reservations, made possible by water conservation.

A group of Apache Indian laborers on the Roosevelt Reservoir is shown in Pl. XVII. B. These men are members of a tribe reputed to be among the most bloodthirsty in the world, but under fair treatment they have responded and have dropped, outwardly at least, some of the more obnoxious of their tribal customs. When paid a white man's wages for a white man's work, they have adopted a white man's clothes and have been not only faithful but have proved unusually intelligent in their work. Without this work of water conservation, these men and their families would have remained as roving "blanket Indians" with no means of self-support, being dependent upon the bounty of the government for their food. By conservation and utilization of the water which rises within the reservation it is practicable for them to become self-supporting citizens capable of performing useful service to each other and to the community.

In reviewing all of these general conditions of reconstruction and the application of the principles of hydro-economics, the most striking fact is that while large results have already been achieved and still larger results are possible for the public welfare, each large project is hampered or blocked by lack of complete information on important details. In other words, research amply supported and scientifically conducted is needed to make real the vision of increased health, comfort and prosperity.

CHAPTER II

WATER IN GENERAL

WHAT IS WATER? What do we know about it and how do we obtain the facts? Every one knows what water is—for every life depends upon it, yet as in the case of other well-known substances in common use, the wider it is known the greater the difficulty of giving complete answers to such simple questions. The word itself probably originated in northern Europe. The Greek equivalent is in frequent use as our prefix hydro- and the Latin is aqua; the use of these terms affording opportunity for a wide range of expressions permitting nice shades of meaning.

The substance as we ordinarily know it and as it forms the basis of life is a fluid, but we may properly consider it as a mineral, a portion of the rocky crust of the earth, but one which melts at a temperature below that necessary for the support of life. It is hardly necessary to more than refer to the fact that from the chemical standpoint pure water consists of two parts of hydrogen and one of oxygen, but as oxygen is about sixteen times as heavy as hydrogen, by weight water consists of one part of hydrogen to eight of oxygen. The combination of these two gases is so stable that to separate them is usually required a somewhat powerful electric current or chemical reaction involving the absorption of considerable heat. It is the most important of all chemical agents, for it takes into solution most of the substances with which it is in contact, and is the universal life fluid. Because of this eagerness in taking to itself portions of other substances it is practically never pure unless artificially prepared.

From the physical standpoint water is also of the highest interest and importance. It is continually in motion, even as a solid; as ice it is moving slowly under the influence of gravity, settling or becoming consolidated by its own weight and almost

imperceptibly flowing toward some lower point. In its change to a liquid it absorbs great quantities of heat and contracts in bulk, continuing to do so until a point of maximum density is reached a few degrees above freezing, and then it expands. These peculiarities are of fundamental importance in the discussion of natural phenomena and of many engineering matters.

An equally interesting and important physical change is that which takes place when water changes into a gas or vapor, again absorbing great quantities of heat and expanding enormously in volume. Upon these changes depend other great natural phenomena; the explanation of weather conditions and of the efficiency of innumerable mechanical devices rests upon a full knowledge of the behavior of water as a gas or vapor under changing conditions of temperature and pressure.

In order to discuss the properties of water, what it is and what it does, an infinite number of ways of approach are offered. Each of the various sciences might be taken up in some arbitrary order such as chemistry, physics, biology, meteorology and others, but for the present purpose—that of considering the economics of water and the application of its properties to pending reconstruction or conservation problems—the arrangement to be followed may perhaps most properly be that of the use or application of water to the human needs and to the public welfare.

Uses of Water. These needs of humanity are infinite in number,—a catalogue of them would fill a book,—but for convenience of discussion they may be classified in several great divisions, in each of which the benefits to be derived through the application of engineering skill in the use of water may be weighed against the probable cost. In the first of these groups almost any cost is permissible since it involves the saving or prolonging of life. An individual in the desert may be willing to give all that he has for a drink of water; a community may be justified in expending every dollar it can borrow to procure the necessary life-giving fluid. On the other extreme, it is often necessary to weigh carefully the anticipated costs against the benefits. The difference of a few dollars of prospective profit or loss may determine the fate of great enterprises. In turn,

the money loss may be offset by considerations of health or æsthetic values which may justify a financially losing venture.

First and foremost come those human needs and uses which relate to the procuring of water for drinking or household use. While man may exist for a time without industry or may live for a month without food, yet the lack of drinking water for two or three days is usually fatal. To enjoy good health the quality must be good and the quantity ample. Thus the procuring of an adequate supply of good water for drinking purposes outranks all other human needs and stands at the head of all plans for conservation, reconstruction or other applications of hydroeconomics.

Second come those uses of water which relate to food production. As in the case of mankind, no animals or plants used for food can live or flourish without an adequate amount of water at the right time. Hence the provisions for watering domestic animals and for regulation of supply to forage and food plants by irrigation, drainage and flood protection rank next after drinking water.

Third, in importance to mankind, is the use—not often recognized, but of growing importance, coming logically in order after the provisions for drinking water and food—of flowing water in sanitary engineering and particularly in the disposal of waste, both sewage and that from various industries.

Fourth in order come the industrial relations, the employment of water in manufacturing, in making steam, in water power and other mechanical ways. These, as well as the uses just noted, involve certain applications of biological as well as physical laws and require a knowledge and application of engineering, agriculture, medicine, and other useful arts.

Fifth in importance, from the standpoint of human needs and development, comes the transportation of men and goods. Incidentally, while this is last in the category of necessities of life, comfort, and prosperity, it ranks first in legal standing, being practically the only use recognized in the constitution of the United States. It thus has precedence in the eyes of the law over many of the more fundamentally important applications of water.

This condition arises from the fact that at the time when the constitution was adopted it was tacitly assumed that there was water enough for every one and that there was no necessity for safeguarding it in the interest of the public or of the commonwealth. Because of this situation there are now presented under the requirements of modern life many problems difficult of solution, in which the present interpretations of common law as well as of statute law relating to water rights have proved serious stumblingblocks to the best employment of the water resources of the country. Thus in order that our knowledge of the physical and biological sciences above noted may be properly applied to engineering and agriculture, it is often necessary that the legal situation be given study. In fact, a certain amount of research must be conducted into the legal phase of some of these subjects as well as into the physical data needed for the solution of many practical problems.

Taking up each of these groups of human needs and uses of water and going back into fundamentals, it is seen that each involves for complete performance a full knowledge of one or another branch of science. Also a little inquiry shows that our present knowledge of this science, while relatively large, is by no means adequate to answer all of the important questions. For example, in the first use of water, that of prolonging life, we come at once into a branch of biological science and immediately find that our present knowledge of the part played by water in many functions of life is but partly employed. Again, in the second use,—that of production of food,—the part played by water in the soil offers a broad field for research.

Where Water is Found. Water is everywhere; it is in, through and surrounding all substances with but few exceptions. It is in the air we breathe, it forms the greater part of the weight of our bodies and of our food, it is essential to all living things, animal or vegetable, and forms a large proportion of the solid crust of the earth, as well as covers the greater portion of it. To adequately study water in all of its varying aspects, in its employment for man's needs and in his occupations, we must traverse almost the entire range of human knowl-

edge and especially go into the various branches of physical and biological sciences, discussing the arts which enable these to be practically applied to engineering, agriculture and innumerable other industries.

Water is not only all-pervasive, but is continually traveling—sometimes very slowly, progressing only a few inches or feet during a year or century, again with great rapidity encircling the globe as the invisible molecule travels in the form of vapor in the upper atmosphere or as a portion of a visible cloud drifts across the continent. At a little slower speed, after descending in the form of rain, it may flow from the higher mountains to the ocean and later wander in great oceanic currents from the equator to the pole and back again; precipitated as snow it may become solidified in the body of a glacier, imperceptibly moving onward. Again, caught in the rocks it may percolate with extreme slowness, being held entrapped perhaps for centuries; absorbed by a plant or assimilated by an animal it may take part in life's activities.[1]

In the same way that it permeates all substances, its study leads the student into fields often apparently far remote from those into which he originally entered. In its economic relation and in the comparison of costs and benefits derived by mankind in its utilization there is correspondingly wide range. No definite limits of cost of its employment can be fixed in advance as conditions change with great rapidity. For this reason it is of great importance that certain standards of comparison be set from time to time that can be used by the engineer and promoter of new enterprises since these comparisons so largely determine human activities, for example, in the works which may be undertaken in the production of food or in providing facilities for commerce. The question whether a given enterprise will be worth what it costs is ever new and compelling.

Science Involved. The number of branches of human knowledge or science concerned with water and its application

[1] The journey of a particle of water is interestingly described by Prof. H. L. Fairchild in a series of articles, entitled, "Adventures of a Watermol," in *The Scientific Monthly* for January, February, and March, 1917.

to the needs of men is so great as to be an embarrassment. It is difficult to decide where to begin in a study of this magnitude; it becomes necessary to arbitrarily select some point in the cycle of changes which lead into the physical and biological groups of knowledge. A beginning might be made by considering water as a rock forming a part of the earth's surface and from this condition tracing its transformation into a fluid and gas.

It is more satisfactory in our study of water, however, to start at the other extreme and begin by considering it as a vapor forming part of the atmosphere which surrounds the earth and as such breathed by all animals and absorbed by plants. In the air it is visible only when it forms in small drops which we know as clouds or fog. In the orderly consideration we may thus begin with the science which treats of water in the atmosphere, or meteorology. This in its lesser meaning is a discussion of those things which are in the air; it treats of the atmosphere and its phenomena, the variations of heat and moisture, the winds and storms.

But the drops of water in the air falling upon the earth quickly pass out of the dominion of meteorology into that of another group of physical sciences known as hydrology or hydrography, geology or geography, and bring into question many matters which are treated under the head of hydraulics, hydrostatics and hydrometrics. In these physical sciences a vast amount of information has been collected but still further research is needed in order to make much of this available for present uses.

Passing to the more intimate needs of water, we come into the group of biological science in which the phenomena are far more complicated and even less understood than in the physical group above enumerated. These have to do primarily with health and vital functions, with the quality and quantity of water needed for drinking and for household purposes. They lead into agriculture and its involved ramifications, to the production of fish and to studies of lower forms of life dependent upon moisture conditions. To enumerate all of these would be unprofitable at the present time, but it is sufficient to call

attention to their wide range and to accentuate the fact that we have hardly begun to make the studies needed for the profitable consideration and use of the facts about us.

In considering "the things which are in the air," the one substance which is of chief interest to us in this connection is water. This occurs mainly as a gas or vapor characterized here as elsewhere by an endless cycle of changes and variations in quantity, quality and appearance. The air may be apparently dry and yet contain a trace of water vapor, or saturated to the point where with lower temperature all the water can no longer exist as a gas and the water falls as rain or gathers as dew.

METEOROLOGY is the oldest of sciences in the sense that all savages, and presumably the prehistoric men, studied the weather and recorded unconsciously or otherwise the changing seasons and the conditions which affected their personal comfort, health, and food supply. In the mind of primitive man the facts connected with the weather and with the movements of heavenly bodies were closely related; the foundations of astronomy and of meteorology were laid together. A mass of observations and deductions more or less systematically arranged has been accumulated from time immemorial; out of these have grown many sayings handed down from our remote ancestors. It is only within recent years, however, that the invention of instruments has made it possible to record the facts of weather changes and to permit accurate comparisons or scientific deductions regarding changes of atmospheric pressure, of heat and cold, with the accompanying variations in clouds and in rain.

While countless individuals have made records of weather changes, these have necessarily been at isolated localities, mere specks on the map. As weather is a matter of changes which take place throughout the entire atmosphere surrounding the globe, these individual observations have had relatively little scientific value. It was only when facilities were offered for simultaneous recording and exchange of information by means of the electric telegraph that it was possible to obtain valuable comparisons of weather conditions over broad areas and thus make deductions from the phenomena occurring at widely sepa-

rated points. Because of this necessity of widespread simultaneous observation it has naturally resulted that the study of meteorology on a large scale or a research of this character has become a function of the general government.

The accumulation of observations on rain- and snowfall, sunshine and cloudiness, pressure and temperature changes, floods and droughts, and their effect upon crop production, industry and transportation is very great; much of it still requires careful arrangement and study. But although this accumulated mass of more or less related data at times seems appalling to the investigator, yet when he begins to get into it he discovers that it is only a tithe of what is needed in the solution of any particular problem, such as that of flood control or of the increase of crop production within any particular area. He must have more figures and is urgently demanding that research be continued into many lines hardly yet touched.

Following along in logical order the course of the water precipitated we pass from the consideration of things in the air, or meteorology, to those of the earth, or geology. Before going into this latter science, there are certain intervening research groups to which reference should be made.

Hydrography and Hydrology. When the rain or snow condensing out from the atmosphere descends upon the earth it soon becomes a part of the surface features and thus passes out of the domain of meteorology, as strictly defined, and becomes the subject of study of another group of sciences usually known as hydrography or hydrology. The difference in significance of these two terms may be best illustrated by following the analogy between the similar words geography and geology. The word hydrography implies a description of water bodies, particularly the survey of coast lines and of the bottoms of harbors, and preparation of charts of navigable waters. The meaning of the word has also been extended to include the mapping of lakes and streams and a description of these as regards their relative size and location.

Hydrology is defined as being more general in nature, being the science which treats of water, its properties, phenomena and distribution over the earth's surface. The term has also

been used with reference to underground water as distinguished from hydrography, which is more often applied to surface water supplies and sources. The point to be observed is that while meteorology considers among other things the water in the atmosphere surrounding the earth, the moment that—as a solid in the form of snow or ice or as a liquid in rain—it strikes the earth, further study falls within the scope of the sciences now described.

Hydrography or the survey of the larger navigable bodies is for the most part a function of the national government, since it alone has the authority and means of charting the navigable waters which by law are under its exclusive control. To a less extent the data on hydrology must be obtained by governmental agencies because of the fact that streams flow independently of state or political boundaries and because of the fact that many interstate industrial relations are concerned. Studies and observations have been somewhat widely conducted by individuals or corporations, particularly in connection with the development of water power. Thus the efforts of employees of the government are supplemented by data privately obtained.

As stated by Meyer[1] this science of hydrology is fundamental to the solution of many problems in water power, water supply, sewerage, sewage disposal, drainage, irrigation, navigation, and flood protection and prevention. Although extending to a large field of engineering science, hydrology itself is founded upon numerous other sciences as well as upon a large body of physical data peculiar to itself.

In the description given by Mead[2] he calls attention to the fact that hydrology "treats of the laws of distribution and occurrence of water over the earth's surface, and within the geographical strata in sanitary, agricultural and commercial relations." He further states: "We must to an extent at least seek information from meteorology, geography, geology, physiography, agriculture, forestry and from the field of hydraulic engineering of which hydrology is the basic study."

[1] Meyer, Adolph F., "The Elements of Hydrology," John Wiley & Sons, 1917, 487 pages, illustrated.

[2] Mead, Daniel W., "Hydrology, The Fundamental Basis of Hydraulic Engineering," McGraw-Hill Book Company, 1919, 650 pages, illustrated.

In this science as in that of meteorology, while there have been accumulated great volumes of data, many of which await compilation, yet the amount available shrinks into insignificance when compared with the growing demands of the engineer who is trying to meet the needs of modern industry. More and more investigation and research are demanded if he is to be prepared for the developments which are waiting upon the obtaining of such facts.

Geography, Geology and Physiography. As indicated above, this group of sciences follows in logical order in the study of the water resources of any large area. The first of these just named is concerned mainly with the features of the earth's surface as they are now found; the second, geology, with the history or way in which the earth's surface has been brought to its present condition largely by water action; physiography gives special attention to the present land forms and the way in which they were produced largely by the influence of water.

Biological Sciences. As we follow the vagaries of water movement from the inanimate world of gases, liquids, and rocks, we quickly pass into the world of life of which we ourselves are a part and concerning whose varied phenomena we know much but have only entered upon the threshold of knowledge. The first fact which confronts us as indicated elsewhere is that life—plant or animal—is dependent upon water, and cannot survive without it, nor prosper except when within a certain relatively narrow range of quantity, quality and temperature.

The ordinary plants flourish and fructify only when the water content in the soil exceeds, say, 8 or 10 per cent and is less than 16 or 20 per cent. Animals need a certain limited quantity, but suffer if this is notably reduced or are quickly drowned by an excess. Thus the general statement may be made that every division of biology, including botany, zoölogy and various subdivisions of these, touches an infinite number of points concerning the occurrence of water—its supply and use.

Application to Human Needs. The discussion of the uses of water to supply human needs ramifies into each of the sciences above enumerated and into fields not yet explored and in which research is needed. These matters may be considered, either

under the somewhat arbitrary classification of the sciences or more properly in the immediate importance of water to human life as described on page 37, viz., first in drinking, second in food supply, and so on through the complicated industries or arts contributing to the health and prosperity of nations as well as of individuals. All of these items fall under the general head of hydro-economics or of water conservation and use. This discussion might proceed along various lines, but for present purposes it is more desirable to take up certain of the larger items out of the strict order of scientific procedure and to discuss such matters as the occurrence of water, the way in which precipitation is measured and how it varies, the effect of forests and mountains, and the disappearance of water into the atmosphere by evaporation.

In reviewing the entire field of water conservation and use from this, the human standpoint, we may then consider:

1. The occurrence of water in nature as described in the sciences above enumerated.
2. Uses of water such as have been developed or may grow out of additional human needs.
3. Legal relations or limitation imposed by man-made laws.
4. Methods of control and use which must take into account the laws of nature and of man with their application in benefiting humanity.

In carrying out this general plan the next subject after the properties of water is that of its occurrence in nature, beginning—as previously stated—with the first visible appearance when the water falls from the clouds and before it strikes the earth in the form of rain or snow or when it is visible as dew.

CHAPTER III

PRECIPITATION

RAINFALL. It is generally assumed that the rain comes from the visible clouds which float above the surface of the earth, but it is not always as well understood that these clouds are formed by water which has been pumped or raised by the sun's energy from the surface of the oceans, rivers or leaves of the forest or fields. Practically all mechanical energy can be traced back to the sun. When we see the great torrents of water rushing down the mountain sides or falling over precipices as at Niagara, we are simply viewing the results of an infinitely small portion of the sun's energy which has been expended in lifting this water from the earth's surface to the clouds. Moreover, it is safe to infer that any change in the quantity of energy continually flowing from the sun may have far-reaching resultant effect on the rain or weather.[1]

To understand fully the action which takes place in the creation of water vapor, in the diffusion of this around the globe and in the condensation of portions from time to time in the form of rain, it is necessary to call attention to the fact that lowering of the temperature may result in condensation of the invisible vapor which exists at all times in the atmosphere. This chilled vapor gathers into minute drops or ice spicules forming fog or clouds. As these particles increase in size and gain in weight they are able to move downward through the supporting air and finally to descend as rain or as snow, sleet, or hail.

The precipitation of water is thus intermittent and is governed by forces far beyond the control of man. This fact has not always been recognized; even today there are many persons, with whom "a little knowledge is a dangerous thing," who

[1] See *Monthly Weather Review*, December, 1918, Vol. 46, p. 574, footnote 5, and January, 1919, Vol. 47, pp. 1-4 (Brooks).

believe that by bombarding the heavens or by the use of some mysterious mechanical or chemical means the greatly longed-for rain may be produced. Rain is also distributed irregularly over the surface of the globe, being often in excess in one locality and deficient in another. It is this irregularity of distribution in space and in time which gives rise to most of the needs of research and of engineering applications of the results of study.

The meteorological discussions[1] now available describe the various factors influencing the formation of clouds and the precipitation of their burden in the form of rain. Confining ourselves to a consideration of the rain after it strikes the earth, the first and most obvious problem is that of measuring the quantity and ascertaining the amount and duration of the rain. It is now generally assumed that if we can make accurate measurements and preserve the records of what has taken place in the past we may be able to predict in a general way what will take place in the future and make provision accordingly.

Prophecies as to the time and amount of rainfall and consequently of the supply of water available for the needs of mankind are of vital importance in many industrial operations. Each farmer, or civil engineer, must be something of a prophet; according to the original sense of the word he must "speak for the gods," interpreting the laws of nature as he understands them. Like the prophets of old the engineers of the present day are educated in the schools to translate and apply "the signs of the times." The point to be emphasized as noted above is that in all of these necessary predictions as to what may take place in the future we are basing our assumptions upon the stability of the range of fluctuations and the fact that the future will repeat the history of the past. It is for this reason that these records of past happenings, whether of rain or of river flow, have their greatest value. While records of rainfall, of floods and droughts may have a certain scientific interest in themselves, yet their real value arises from this assumption. At the same time the fact should be kept clearly in mind that this is

[1] "Introductory Meteorology," prepared and issued under the auspices of the National Research Council, 1918. Also, Humphreys, W. J., "Physics of the Air," *Journal of Franklin Institute*, Vol. 185, April and May, 1918, pp. 517-538, 611-647.

only an assumption and that the rain and the river flow are rarely twice alike.

In order to obtain as correct conceptions as possible regarding these fundamental assumptions it is desirable to consider the cause of precipitation. To this end the following extracts have been made from a statement prepared by Dr. Charles F. Brooks, meteorologist, United States Weather Bureau.

CAUSES OF RAINFALL. Many have been the speculations as to the cause of rainfall. In biblical times, the doors of heaven were opened and the rain descended. Observers of the sixteenth and seventeenth centuries, however, were not satisfied with such a simple explanation and substituted some which were more suited to their everyday experiences on the earth's surface. Thus, Dr. W. Fulke in his "Booke of Meteors," England, 1563 (later edition, 1640), explains that rain clouds are condensations of wet vapors, others of dry ones. Dark clouds are said to be dirty; rainfall comes when heat dissolves the cloud, letting out the water inside. Hail is from great heat which makes large raindrops and this comes together and freezes into square blocks.

In "Speculum Mundi," 1665, the author, John Swan, tells us that the devil is the cause of "prodigious rains," such as falls of "blood," fishes, pebbles, and frogs. The red rains actually are red from dust or algæ; rains of fishes, pebbles, and frogs are made possible by the occurrence of waterspouts, dust whirls, or tornadoes (cf. McAtee, "Showers of Organic Matter," *Monthly Weather Review*, May, 1917, pp. 217-224). Swan says also that the hail of summer is from violent antiperistasis which brings great cold from above, forced up by the lower great heat. This heat also makes snow and rain. "Siamese children believe that when many angels get into the same bath at the same time, water runs over the side, and it rains." (*Symons' Meteorological Magazine*, January, 1918.)

The first scientific explanation took definite form at the end of the eighteenth century (1784) when James Hutton, a Scotchman, published a theory of rain. His idea is that rain is caused by the rising of warm, moist air into the cold upper air. The mixture of portions of the atmosphere at different temperatures

and sufficiently saturated with moisture was thought to produce most of the rain. He recognized that wind, temperature, and pressure have effects on rainfall. This apparently reasonable theory was accepted for a long time as the principal cause of rain. Computations, however, of the possible rainfall from mixture showed that this could yield little. If saturated air at 10 degrees and 20 degrees Centigrade are mixed in equal volumes, the result of the mixture will be air with a temperature of about 15.3 degrees Centigrade, and precipitated moisture amounting to 0.2 gram per cubic meter.

Radiation is hardly more effective than mixture in producing rainfall, since it can rarely cool a great thickness of air sufficiently to produce appreciable precipitation. In some thick radiation fogs, there may be a drizzle which in the course of hours may produce 0.01-0.05 or more inch of precipitation.

The fact that rainfall follows great battles was noted in early Roman times; but recently the occurrence of such rain has been ascribed to the explosions, or perhaps to the added number of condensation nuclei added to the atmosphere. That the occurrence of rainfall after battles is no more frequent or extreme than after any outdoor operation which is planned and carried on in fair weather has been proved many times, or, to state the matter in another way—the period of fair weather favoring or inducing battles or other field work, will probably be followed by showers both in times of peace and of war. Dr. H. R. Mill, director of the British Rainfall Organization, has shown the practical impossibility of the power of even tremendous gunfire or explosions, to affect appreciably the almost infinitely more powerful processes of the atmosphere. Computation shows that the quantity of air which must have passed over England and Wales in December, 1914, exceeded 1,300 trillion (million times million) tons. "The amount of force required even to deviate the direction of moving masses of this magnitude is surely far beyond that which can be exerted even by nations at war."[1] In a later statement,[2] Dr. Mill directs attention, among

[1] Mill, H. R., *Quarterly Journal*, Royal Meteorological Society, October, 1915.

[2] *Symons's Meteorological Magazine*, February, 1918; abstract in *Geographical Review*, January, 1919, p. 51.

other points, to the fact that much emphasis has been laid on the relative wetness of 1915 and 1916 in southeastern England: the year 1917, when the war was in a very intense phase, had a nearly normal rainfall. Perhaps the final blow to the idea that artillery produces rainfall was dealt when in the two or three weeks following the beginning of the great German drive in March, 1918, the battlefield in France was practically rainless. Surely this tremendous artillery battle should have produced rain if rain can be produced in this way.

These processes—mixture, radiation, artillery fire—can at most produce but slight cooling of large masses of air. The considerable cooling of great masses of air necessary to produce heavy general rainfall can be brought about only by convection. This was discovered only 50 years ago. Most people still think that it rains because the warm lower air ascends to a cold region where it is chilled by its surroundings. A more correct conception is that rain is formed because the warm air in ascending necessarily expands and in so doing is cooled by its own internal action, resulting in the loss of much of its moisture; that is, the rain is the result largely of "convection." If a cubic meter of air saturated at 15 degrees Centigrade were raised to an altitude of 1,000 meters, the resulting cooling would precipitate about 2 grams, ten times as much as was obtained in the example of the effects of mixture given on page 50. The elevation of great masses of air to several times 1,000 meters is of frequent occurrence in cyclones and thunderstorms. Thus, it is obvious that mixture and radiation are to be considered as only minor factors in the production of rainfall, the principal cause being convection.

Snow, sleet, and rain are closely related forms of precipitation. Much of the rain that reaches the earth is made up in part at least of moisture originally condensing as snow. The precipitation taking place in clouds at temperatures below freezing seems to be of this nature. When such snow, however, falls into air whose temperature is above freezing, it melts and becomes rain. If the melting is interrupted by the entry of this partially melted snow into a layer of air with a temperature below freezing,—as is not infrequently the case in winter,—the

partially melted snow freezes and becomes sleet. The form of sleet can be as diverse as that of snow in all stages of melting, from the hard, white, angular pieces of ice, to nearly spherical or hemispherical drops of ice whose only indication of previous snow condition is to be seen in the minute bubbles included in the crystal.

RAINFALL MEASUREMENTS.[1] Our conceptions of rainfall and snowfall have been obtained mainly from tradition, hence we are frequently misled by erroneous assumptions. Everyone is affected in his business or pleasure by the weather, and particularly by the excess or absence of precipitation. We remember the unusual occurrences as these stand out prominently in our recollection of past events. Naturally we turn to the oldest inhabitant for a statement as to what are the prevailing characteristics of the locality; he narrates the conditions which have influenced him most strongly. Often this is about the only source of information available concerning the rain- or snowfall during the past generation on large areas of sparsely settled country and particularly in the mountain regions where it is desirable to construct reservoirs for conservation of water.

For engineering purposes it is now appreciated that relatively little reliance should be placed upon the recollections of the oldest inhabitants. While these are in a general way indicative of extremes, yet they must be approached with a questioning attitude because of the fact that human memory without verification is quite fallacious. It has been found essential therefore, in order to obtain reliable data, to search for more definite records and to establish at the earliest practicable date suitable measuring devices for ascertaining the amount of precipitation and the time of its occurrence.

There have been many devices employed in measuring rainfall or snowfall, some of them quite ancient and most of them very simple. The one most commonly employed is a vessel or pan into which the rain falls; the depth is then measured directly. It is obvious that the sides of this pan should be vertical and that it should not be so shallow as to permit the rain to splatter out. The depth of water obtained in this way may be

[1] See also *Monthly Weather Review*, May, 1919, pp. 294-296.

ascertained by direct measurement or more accurately by weighing or pouring into some measuring device. For ease and accuracy of measuring, however, a standard rain gage has been devised in which the open pan, usually 8 inches in diameter, instead of having a flat bottom, is provided with a conical-shaped funnel which leads into a tall narrow compartment whose area is one-tenth that of the upper rim of the pan or collecting vessel. Thus the depth of the water in the lower compartment into which the rain flows is ten times that of the equivalent amount of water in the upper portion. The depth being thus magnified by ten can be readily ascertained to one-hundredth of an inch. The point to be emphasized is that we are not measuring the rainfall on a county or township or even on an acre of land but only in a particular vessel. We assume that this represents a large area but this is only an assumption made for lack of better ways of obtaining the needed facts.

It is obvious from the nature of the case that the rain gage is not an instrument of precision. For measuring rainfall the device is fairly effective, but in giving the water contents of snowfall great inaccuracies are usually involved. To obtain data on the general depth of rainfall on a small area, it is necessary to have the gage so placed that:

(1) The splash from the ground will not enter it.
(2) The drift of rain off other objects will not go into it.
(3) Other objects will not exclude rain from it.
(4) Peculiar wind eddies will not affect the catch.
(5) The opening of the gage will be horizontal and therefore represent a level surface of ground.

For snowfall, if snow has fallen during a wind, the way to get the water content is to cut an average cylinder, or several of them, out of the snow-cover and measure the water content either directly or by weighing. When snow and rain fall together, with a high wind, it is practically impossible to find out how much precipitation occurred. The gage will catch the rain and sleet and some of the snow, the ground will retain the snow, but perhaps let the rain go.

Irregularities in Measurement. Rain gages placed essentially side by side may give readings differing by 5 per cent and

when only a few hundred feet apart by more than 10 per cent in annual catch. Thus, it is well to remember that rainfall records cannot be considered as accurate to the nearest hundredth of an inch, even though stated in these terms, nor even to the nearest inch if annual totals are considered. Nevertheless, we must accept these records on the faith that they are probably right, or at least as near right as we can get them.

For purposes of comparison, it is essential that the same period of years be used and that conditions of exposure of the gages be essentially the same. Rainfall varies so much from year to year that at the same station the average from a 19-year period may differ considerably from that of a 20-year period.

In mapping rainfall, the interpretation of the results on the basis of the known effects of topography on rainfall is essential if a reliable picture of the distribution of rainfall is to be made. The rainfall lines (isohyets) should be drawn with full consideration of the influences of topography but without in any way running counter to the indications of the measured records.[1]

The daily and annual distribution of rainfall may be peculiar in certain places because of local conditions. For large regions there may be large departures of the monthly rainfall from the average on account of changes in the positions of the centers of action, or because of long-continued changes in the temperature of the water surfaces which usually supply the moisture.

Torrential rains result from strong convection or rising of great bodies of air. In thunderstorms in the temperate zone, there may be more rain in an hour than is possible in the tropics where there may be more moisture available for precipitation but where the processes may not be so strong. Dr. O. L. Fassig (*Monthly Weather Review*, June, 1916, vol. 44, 329-336) has found that it can rain harder at Baltimore, Maryland, for a short time, than it can at San Juan, Porto Rico; but that torrential rains can continue longer at San Juan than at Baltimore. The heavy rains in the tropics come with tropical cyclones. Even in the United States such tropical cyclones may bring much rainfall. On September 28, 1917, Robertsdale,

[1] See "The Preparation of Precipitation Charts," *Monthly Weather Review*, 1917, Vol. 45, pp. 223-235.

Ala., received 17.46 inches in a day;[1] and on July 14-15, 1916, Alta Pass, N. C., in the southern Appalachians had 22.22 inches of rainfall in twenty-four hours. In the Philippine Islands at Baguio there is a record of 45.99 inches in twenty-four hours during a tropical cyclone, July 14-15, 1911. Destructive floods occur under such conditions.

The cloudbursts of the deserts, and even of the more humid parts of the country, are truly cloudbursts. For example, a strong desert dust whirl may rise higher and higher until at perhaps 3,000-4,000 meters a cloud begins to form. With renewed energy from the latent heat of condensation in the whirling, rising column, the cloud grows. Rain begins to fall, but a large proportion is held in the cloud by the air rising faster than the rain can fall, viz., 8 meters per second. Some may come out of the bottom of the cloud but it is quickly evaporated and carried up for condensation again. Finally, the whirl may encounter a mountain and go to pieces: down comes all at once the rainfall accumulated during some hours. This shows why it can rain at several times the rate at which the moisture can be precipitated in the rising column of air.

Not only is the rainfall varying in quantity from minute to minute, but at the same moment it varies in rate even over a single square mile. It is no uncommon experience to drive along the country and find a portion of the road wet from recent rain and in a mile or two another stretch of road comparatively dry. It may rain severely in one ward of a city, flooding the sewers, and other wards may receive merely a sprinkle. Thus we can hardly expect that any two rain gages which are not within a few feet of each other will receive the same amount of rain. More than this, we find by observation that a gage placed on the ground receives a larger quantity than a similar gage exposed on top of a building.

It was formerly assumed that more rain actually fell on the ground than on the top of a building, but it is now generally conceded that the difference in amount received by the gages is due principally to air currents which blow diagonally into or

[1] See table of excessive rainfalls in periods of about a day, in *Monthly Weather Review*, May, 1919, Vol. 47, p. 302.

across the opening of the gage. Near the ground the air currents are reduced and the rainfall is more nearly normal. In certain measurements made by the Weather Bureau, it is shown that a gage at an elevation of 43 feet received 75 per cent of rainfall, at 85 feet it received 64 per cent, and at 194 feet above ground the gage recorded only 58 per cent of the amount which fell in a gage placed on the ground.

In interpreting and applying the results of measurement of rainfall, it is highly important to ascertain as completely as possible the position of the gage with reference to its height above ground and particularly as to the shading effect of buildings, trees or other obstructions influencing the behavior of the wind. Neglect of these precautions has led to many popular fallacies and occasionally to serious blunders in planning works.

Periodic Fluctuation. In studying the data available concerning precipitation it is quickly apparent that one year of relative drought may be followed by another even more dry. In the course of a few years, however, there is always a return to average or normal conditions. By taking a long range of observations it is seen that there is occasionally a series of wet years followed by a series of dry years. These are sometimes termed nonperiodic fluctuations because of the fact that these periods are of irregular length.

It also appears from a study of the records that each year forms a new combination and that the rainfall in time of occurrence and in quantity is quite different from that of any other year. The average for, say, five years or ten years is usually somewhat above or below that of the preceding or succeeding similar period. If, however, the observations are available for, say, fifty years, it appears as though most of the ordinary vagaries of the weather had been exhausted; the average for any one fifty years is approximately the same as that for a similar period. In making such comparisons, however, it must be recalled that the precision of the observations extending over any one period of fifty years necessarily differs from that of another fifty-year period because of changes or improvements in instruments, in methods and in surroundings as well as in the personnel of the observers.

The point to be noted is that observations of precipitation extending throughout five years or even ten years may or may not be representative of conditions which will prevail later. If, however, a fifty-year range is available, then considerable confidence may be placed upon the results as it is quite probable the the extremes of drought or flood have been experienced. For lack of definite data it is customary to make allowance of at least 20 per cent increase in the extremes of drought or flood for measurements which have been continued for five years and of 10 per cent for measurements over a period of ten years.

It is, of course, impossible for an engineer planning works of conservation to delay for ten years or even for five years to obtain data on precipitation and related river flow. He must utilize the figures at hand and make allowance on the side of safety—keeping in mind the fact that fluctuation does occur, and that careful study should be made. He should continually add to his knowledge of the changes which may take place from day to day, compiling these in monthly and annual totals so that on the basis of these data he may make predictions, within proper limits, of the conditions which the works of water storage may be called upon to meet.

In making such predictions it is important to bear in mind the fluctuations as above noted and to consider what has been the general trend of these changes. Taking recent geological observations, there has been no doubt a marked change in climatic conditions since the glacial period. The time which has elapsed since this period can hardly be expressed in years, but may be roughly considered as extending over tens of thousands of years rather than a lesser number. Man's historic period compared to this is short, especially that of recorded data, but it is possible from the study of long-lived vegetation such as the giant trees, Sequoias, to arrive at the conclusion that the rainfall fluctuations during the past few hundred years, on the whole, have not been much greater than during the past fifty years. In other words, trees several hundred years in age are found in many parts of the country, a study of whose annual rings of growth shows that the rainfall and temperature could

not have been greatly different from those which now prevail in the same locality.

Many students of the subject have attempted to deduce some rule covering the variations in precipitation which now take place and to connect these with other phenomena, such as the intensity of the sun's radiant heat as indicated by the sun spots. Some have arrived at a cycle of seven years, others at eleven, and Bruckner at thirty-five years.[1]

These fluctuations and theories concerning them are interestingly described by Ellsworth Huntington in his book, entitled, "Palestine and Its Transformation." He there brings out the various hypotheses of the progressive changes of climate, showing by simple diagrams the fundamental deductions from the observed facts. On the one hand, it is argued that there is a nearly uniform shrinkage in water supply; on the other hand, it is urged that this rate of change varies from century to century. Much of the data has been obtained from a study of forest growths but still further research is evidently needed.

The conclusions to be derived from these various discussions of methods and results of rainfall measurement are in general that climate is practically fixed so far as it is of concern in preparing the usual engineering plans, but, to determine the range of the weather for any one locality and accompanying phenomena within these apparently fixed climatic limits, it is necessary to have observations extending over possibly fifty years in succession. Experience has shown that in any period of a half century, practically every extreme of weather may be expected to occur, such as has happened in the previous century or which may properly be predicted for the next one hundred years. For any shorter period, for example, of five or ten years, the averages may be misleading and a considerable factor of safety should be added to cover possible contingencies.

In all these matters additional investigations are needed not only for the purpose of obtaining data from original obser-

[1] Newell, F. H., "Water Supply for Irrigation," 13th Annual Report, U. S. G. S., Part III, "Irrigation," p. 25.

Bruckner, Dr. Edward, "The Settlement of the United States as Controlled by Climate and Climatic Oscillations, in Memorial Volume of Transcontinental Excursion of 1912, of American Geographical Society," p. 125.

vations but more than this in connection with the digesting of the array of facts already accumulated which are only partly interpreted.

Dew and Frost. The formation of dew or frost occurs when the temperature of an object falls below the dew-point of the air immediately in contact with it or on plants when exudation of moisture takes place more rapidly than evaporation. Dew is highly important in dry countries, for there it may be the only moisture which plants and animals have available for their support for long periods of time. The importance of frost is associated with the damage done by the low temperatures. Light air movement and dry, clear air at night favor the formation of frost. Light air movement is favorable not only because the objects are allowed to cool to a temperature appreciably below the air temperature, but also because local frosts are connected essentially with local "air drainage." Soon after sunset, cold and dense air, cooled chiefly by contact with the ground and to some extent by radiation, drains slowly down the slopes into the valleys and low places. Strong winds mix the air and thus prevent the occurrence of local frosts. Dry, clear air aids local frosts because the dry air favors rapid radiation, and because the latent heat of condensation which accompanies the cooling of moist air will check the fall in temperature.

For convenience in frost studies, Alexander McAdie has devised a "saturation deficit recorder." This instrument is essentially a hygrograph mounted on the pen of a thermograph. The thermograph indicates the maximum weight of water vapor possible in the air at the temperature prevailing, and the hygrograph indicates the percentage of saturation. Methods of protection, distribution of killing frosts, and dates of occurrence are matters chiefly of interest to agricultural meteorologists.[1]

Sky Signs. Farmers and mariners know the sky signs; but they do not know them as well as they might could they under-

[1] See Frost folio, "Atlas of American Agriculture," 1918; review, *Monthly Weather Review*, November, 1918, pp. 516-517, and *Geographical Review*, May, 1919, pp. 339-344; articles in the *Monthly Weather Review* and *Geographical Review* during the past two or three years.

stand the processes the clouds indicate. Here is an almost untouched field for further research and diffusion of information, which is attractive not only because it is interesting and easily accessible, but also because it is so full of promise for advances in local weather forecasts. The form of the cloud generally gives some clue to the processes by which it is being formed; its movements indicate the winds by which it is carried, and in many cases show the relation between two winds, which may be indicative of further condensation and subsequent precipitation. Thus the rapid growth of cumulus clouds on a warm summer day, or of the flatter strato-cumulus shortly after sunrise on a winter day, is frequently followed in a few hours by showers or snow-flurries which may or may not reach the earth.

The appearance of "rafts" of alto-cumulus clouds, with a smooth, basal undulating sheet, obscured here and there by the lower parts of a snow curtain falling from higher level of condensation, or even by streams of snow falling from the balls themselves, indicates strong processes of convection which are likely to be followed by precipitation which will reach the earth's surface. Similarly, the progressive thickening of the thin, white, cirro-stratus sheet, hazily mottled here and there with cirro-cumulus balls, into alto-stratus and alto-cumulus is likely to be followed by rainfall when the cloud has thickened still further. Stratus clouds and low, indefinite sheets of early morning strato-cumulus clouds are generally not indicative of processes which will produce rainfall. They are likely to break away in the warmer hours of the day.

Forests and Mountains. The kind of civilization of a country is shown by the way in which its forests are given care and attention. Much of the prosperity, health and comfort of future generations lies in the present effective protection of forest growth. The degree to which thought is now being given to the needs of those who come after us measures our own growth in the scale of civilization. In considering reconstruction or conservation problems, the forests have peculiar interest, not merely from the standpoint of immediate use, but more than this, from their peculiar relation to future generations of men

and as to our attitude in perpetuating and handing on to others in even better condition the good things which we now enjoy.

The primitive man is concerned with his immediate daily needs and seldom attempts crop production. As he comes up in the scale his vision increases and he plants the rapidly growing corn. Later in a semicivilized state he protects or adds to the fruit and nut trees which may not come into bearing for several years; but it is only when mankind attains a high degree of altruistic ideals that he plants or guards forests and similar resources, knowing that a crop can be had perhaps only once in a lifetime or that the full value will be received by his grandchildren or by those who take their places.

Hydro-economics, so far at least as it is concerned with the conservation and use of water, is intimately related to forestry, with the care, preservation and enlargement of forest growth, especially in the mountains and in areas where the soil has little value for the production of other crops. It may be said that the earliest and strongest supporters of a national or state policy are the engineers and men of vision who see in the protection and use of the forests the best guarantee for the continued enjoyment of certain uses of water. The most notable example is that of the conservationists—or hydro-economists—who urged action by the Congress of the United States in setting aside for forest protection great areas of public land with the object not only of furnishing a supply of timber, but of affording protection to the headwaters of important western streams.

This achievement, with reference to the public lands, has been supplemented by activities leading to direct Congressional appropriations for purchasing large tracts of privately owned forest land in the White Mountain and Appalachian region in the eastern and southern portions of the United States, where there were no public lands, but where it was believed that the public interest demanded that forest growth be perpetuated. The latter action was taken in accordance with the authority granted to Congress by the Constitution, which gives to the United States the control over commerce and of navigable streams. The forest lands have been purchased under the

theory that the maintenance of navigation can be better assured by the protection of the woodland cover and consequently assumed reduction of erosion of the soil and of filling up of the navigable channels.

Not only has the Congress of the United States taken an interest in the forests and in their protection, as part of its duty to the public, but also the individual states and even municipalities have made forest reserves, some antedating the action of Congress. New York, Pennsylvania, and other commonwealths have their state forests, designed not merely as pleasure grounds or breathing spots for the people and for the protection of bird life and wild game, but also to aid in the more effective control and use of water resources in the many ways of municipal supply, irrigation, power development and soil protection.

One of the most important questions in connection with water conservation by storage of floods is the influence of mountains and forests upon the quantity of water which may be available. In discussing the occurrence of water it has been noted from the earliest times that the inequality of the earth's surface has a great influence upon the precipitation of water from the atmosphere. There is unquestionably a close relation between mountains and rainfall.[1] Whatever the explanation may be it is a well-known fact that the precipitation is usually greater upon mountains and usually increases in depth as the mountain is ascended.[2]

As a consequence of the relatively heavy precipitation on the mountain slope there is usually a dense growth of vegetation—the upper limit being set, in the case of high mountains, by the extremely cold and desiccating winds of the upper atmosphere into which the summit rises. The fact that forests do occur upon mountains even in arid regions has been used as the basis of an argument to the effect that forests increase the precipita-

[1] See "Atlas of American Agriculture," Part II, "Climate," Advance sheet 1, average annual rainfall of the United States, reproduced, with discussion by R. DeC. Ward, *Monthly Weather Review*, July, 1917, Vol. 45, pp. 338-345.

[2] See Henry, A. J., "Increase of Precipitation with Altitude," *Monthly Weather Review*, January, 1919, Vol. 47, pp. 33-41.

tion. Careful investigations have been made in various parts of the world, particularly in Europe and in India, but the conclusions are rather negative in character, the general opinion being that while there may be a somewhat greater precipitation in the forests than on a similarly situated open area, yet the difference is so slight that it may be due to errors in observation.[1]

Whether or not the presence of forests induces a larger precipitation, there is little doubt that the forests as a rule tend to conserve the water which does reach the ground. They render the condition of water storage far more satisfactory than would be the case if the mountain slope were denuded of tree growth. So strong is this belief that, in the eastern part of the United States in the Appalachian region of the south and the White Mountain region of the north, the United States, as above noted, is purchasing large tracts of forest lands at the headwaters of important navigable rivers with a view to protecting these forests and maintaining them in good condition because of the direct or indirect beneficial influence upon the stream flow. These effects come in part by actual conservation of water in the soil and among the roots of the trees, but more largely by the prevention of rapid erosion and by reducing the washing of the soil from the mountain slopes into the natural lakes or artificial reservoirs and into the stream channels. The soil thus eroded becomes not only lost to the country from which it is removed, but more than this is a distinct injury in filling up reservoirs and in forming shoals in the navigable waters.

Throughout the arid west nearly every community in which irrigation is practiced is asking that the forests at the headwaters of the streams be more completely protected. To this end it is urged that the grazing of cattle and sheep be so regulated as to prevent the close cropping of the herbage or overgrazing to an extent such that the smaller plants are destroyed.

[1] For many years rainfall and other meteorological observations have been made in the forests in the vicinity of Wagon Wheel Gap, Colo., on slopes similarly exposed. Now one slope is soon to be deforested, and the observations continued as before. At the end of this experiment the results may settle at least some of the controversy concerning the effects of forests on rainfall.

It has been shown by practical experience that such regulation can be effected and that instead of reducing the number of sheep which can be fed upon a given area, it is possible with sensible management gradually to increase the number and at the same time afford needed protection to the soil.

The conditions which exist in the state of nature are well illustrated by Pl. XVII. C, showing in the foreground one of the natural lakes such as are to be found in the mountain valleys surrounded on all sides by timber-covered slopes. The particular view is of Keechelus Lake, one of the several bodies of water at the head of Yakima River in the Cascade Mountains of the state of Washington. This and other lakes have been converted into reservoirs by building earth dams at the outlets, as stated on page 166. In this case the wooded slopes have been included in the national forests to be maintained indefinitely, not only because of the value of the timber to be had from time to time, but because of the beneficial effect upon the reservoirs, notably by the prevention of erosion of the hillsides.

Many problems of immediate importance in the prosperity of large communities are presented by the phenomena of forest growth and methods of maintenance. Additional research is needed, particularly into the economics of the handling of forest products and into the relation which public health and comfort bear to the forests as recreation grounds as well as into their influence upon water supply.

The whole subject of relation of forests to run-off has been discussed from time to time by various engineers and students, the most notable contribution to the subject being that by the late General Chittenden, who brought together a concise statement of our present state of knowledge of the subject.[1]

[1] Chittenden, Hiram N., "Forest and Stream Flow," *Transactions of A. S. C. E.*, Vol. 62, p. 245.

CHAPTER IV

EVAPORATION

A force is at work day and night, summer and winter, steadily robbing water from lakes, streams, trees, animals, and all objects which contain it. A study of this activity and a knowledge of its results are fundamental in most of the construction problems which are concerned with hydro-economics. Man's ability to use water in all of its varied forms and applications is confined largely to that portion of it which is left after evaporation has taken its full share. This is a conception to which full weight has not been given in many scientific discussions. We have recognized, of course, that there is such a thing as evaporation, but its powerful and far-reaching influences have not been fully appreciated nor the fact that we can enjoy the use of only such water as nature may condescend to leave after her toll has been taken.

Evaporation is in many ways the counterpart of precipitation. While, on the one hand, nature is intermittently pouring down water from the clouds or is furnishing it imperceptibly in the form of vapor, at the same time there is being withdrawn in every direction a steady flow of water back to the air. We have here a powerful force influencing human, animal and vegetable activities and one which may be converted into a beneficial servant in many industries. That is to say, evaporation, while robbing us of water which might be usefully employed, at the same time is performing innumerable necessary operations, since all the functions of life depend upon it. Additional benefits may be had when widely employed by artificial application, such, for example, as in the drying and preserving of fruits, vegetables, and other food materials. In many so-called practical ways, we have the problem of controlling evaporation and turning its activity to economic ends in promoting commerce and industry.

As soon as the rain strikes the earth, a portion of the moisture at once returns to the air. The quantity which thus disappears at any moment may be small but, being continuous even during the rainstorm itself, the total loss amounts to a considerable portion of the rain which descends. Even from snow or ice there is usually a small loss as the atmosphere is greedily absorbing moisture from all objects containing water. The only exception is when the air is completely saturated; but this seldom occurs; during the prevalence of a storm the layer of air near the earth may be taking up water while the oversaturated higher layers of the atmosphere are giving it out.[1] In dry climates such as those of the western part of the United States evaporation is very active, drinking up the waters of the rivers to an extent such that many of them are overcome by the thirsty air and are never able to reach the ocean.

In all estimates of water available for storage or for use by plants or animals we must first make allowance for the quantity which is demanded by the surrounding atmosphere. This simple fact has not always been appreciated, namely, that the run-off or quantity of water available is the residual after evaporation has taken its toll from the rainfall. For many years engineers have tried to arrive at a ratio between the amount of water that falls in the form of rain and snow and the quantity which runs off the surface. They have assumed, say, that 30 per cent of the total rainfall flows off the land in the New England states, and from this down to 3 per cent or even less in the arid regions. There can be no fixed relation of this kind because the quantity evaporated has no direct dependence upon the quantity precipitated.

The condition of the ground governs largely the amount of water which returns to the air by evaporation. If the surface is open and porous or covered with grass or other vegetation, the rainfall is enabled to run in or soak the ground and saturate the subsoil. If, however, such a surface is packed hard and the vegetation eaten down or destroyed, for example, by bands of sheep as shown in Pl. IX. A, then the water is prevented from

[1] *Monthly Weather Review*, March, 1910, Vol. 38, p. 1133.

running in and, on the contrary, runs rapidly off the surface, causing sharp, sudden floods which carry away much of the finer soil. The losses by evaporation under these conditions, it is true, are reduced, but at the same time the destructive run-off is increased.

From all moist surfaces molecules of water, particularly those which have the greatest energy, or heat, are continually escaping. This loss tends to lower the average temperature of the water particles which remain, or as more commonly stated, heat is consumed in this process. The rate at which evaporation will take place depends on the difference between the vapor pressure of the moist surface and that of the air immediately in contact with it, also on the atmospheric pressure. Wind becomes a factor in that it maintains at a maximum for the general masses of air the differences between the vapor pressure of the water surface and that of the air. Sunlight tends to increase evaporation by supplying sufficient energy to the water surface to maintain evaporation, and at the same time even to raise the temperature of the evaporating surface. The relative humidity of the air has little direct influence on the rate of evaporation—as is well illustrated by the way in which a warm, moist surface can throw into the air much more moisture than that which the temperature of the air will allow to remain in the vapor state. The kettle throws out steam because the vapor pressure of the water in it exceeds that at which the vapor in the air can be saturated.

The amount of evaporation which will occur from the surface of a reservoir, for instance, is a complex function not only of the atmospheric pressure, vapor pressures of the air and water surface, and wind velocity, but also of the area of reservoir and the roughness of its surface. Various formulæ have been devised to express these relations, but it is evident that there is still much to be done in observing the elements of evaporation before we can apply these general conclusions in such way as to estimate accurately the amount of loss which may take place from any kind of a moist surface. Maps showing the evaporation losses from large areas of land or water have not yet been drawn with any considerable degree of precision as comparable data are

lacking. (See B. E. Livingston's isoatmic map of the United States, "Plant World," 1911, Vol. 14, and article, pp. 205-222.)

The total evaporation of the world is of some interest. Since the ocean covers three-fourths of the globe it is the surface from which most of the evaporation in the atmosphere takes place. W. Schmidt (Bulletin American Geographical Society, 1915, p. 695) has computed the mean daily evaporation of oceanic waters to be 2.07 millimeters (0.08 inch) or 27 inches per year. About 11 per cent (net) of this water vapor probably goes over the land. The rainfall over the oceans is estimated to be the equivalent of only about 90 per cent of the evaporation, a depth of 69 centimeters (27 inches) annually. The average over the lands is probably 92 centimeters (36 inches), of which only about a tenth is from the precipitation of water evaporated first hand from the ocean. This seems reasonable when it is remembered that the run-off in streams is generally less than a quarter of the rainfall. On the average, it seems that the flow of the Mississippi by St. Louis is no greater than the total amount of water falling as rain on the state of Missouri. Thus it seems direct evaporation from the oceans supplies the moisture for about three-fourths of the world's rainfall, while that from the lands and inland waters supplies the other fourth.

As the surface of the earth is the sole original source of water vapor in the atmosphere, the decrease with altitude is naturally a little greater in the free air than on mountains. Roughly, at an altitude of 2 kilometers, or over a mile, the content is half of that at sea level; at 3 kilometers, or nearly 2 miles, it is one-quarter (on mountains, one-third); and at 8 kilometers, or 5 miles, 1 per cent of the sea level content. Under usual conditions in middle latitudes, a mountain range but 2 kilometers, or over 6,000 feet, high will allow only half of the water vapor to pass over; the rest is precipitated. In general, the absolute humidity over deserts is but slightly lower than that over other regions, even though the relative humidity is only from 25 to 50 per cent. There is enough moisture in the air to make appreciable rainfall, but it takes extraordinary atmospheric action to precipitate it. Rain makers, or rather the people who hire them,

seem to fail to realize the tremendous amount of power required to cause such precipitation in the arid and semiarid regions.

Evaporation Measurements. Losses in volume or weight of a certain mass of water may be measured directly or the evaporation estimated by noting the rate of cooling. The instruments devised for this purpose are generally known as evaporimeters or "atmometers" from the Greek word *atmos* meaning steam or vapor. The kind of atmometer depends upon the purpose for which measurements are being made. Thus, the engineer uses an open pan atmometer while the student of plant life wants a porous cup or some other device more nearly imitating the action of the bodies whose evaporation losses he desires to obtain.[1]

The open pan atmometer filled with water may be set up on land or may be made to float on a reservoir or lake surface. The water losses from damp soil or plants may be obtained by employing pans or pots of such form that they can be filled with soil and then weighed from time to time to ascertain the amount of water which is received from the rain or other sources and the loss which takes place by evaporation or by transpiration from the plants which are cultivated in the soil contained in the pots.

For purposes of water conservation, especially in preparing plans and estimates for storage works, it is necessary to have some approximation of the quantity of water which escapes from the surface of the proposed artificial lake. It is known that the evaporation increases with the rise in temperature and with the wind movement; hence observations are made of these factors.

Various efforts have been made to measure the depth of evaporation directly from pans so arranged as to float in the water—these being maintained at the same temperature as that on the surface of the pond or lake. Accurate measurements of the amount evaporated from a pan are not easily obtainable because of the many accidents to which an apparatus thus exposed may be liable. The effect of the rim of the pan, even

[1] See "A New Evaporimeter for Use in Forest Studies," by C. G. Bates, *Monthly Weather Review*, May, 1919, Vol. 47, pp. 283-294.

though projecting only an inch or two above the surface, is quite appreciable.

The United States Weather Bureau has carried on investigations of evaporation losses, particularly in various parts of the West. In one series of experiments they floated shallow pans not only upon the surface of the water, but placed them on the ground and on towers so arranged that the pans would be at different heights from the surface of the ground or of the lake itself. A view of one of these towers on Salton Sea in southern California is given in Pl. III. A, and a more distant view of the sea itself in Pl. III. B. Among other facts it has been apparently demonstrated that a large body of water loses in depth only about 0.7 of that from a pan floating on the surface.[1]

Standard Gage. As a result of these investigations the effort to make measurements of evaporation from the surface of pans floating in a reservoir or lake has been practically abandoned. The difficulties and uncertainties involved were found to be too great. The Weather Bureau has now adopted a standard type of apparatus as shown in Pl. III. C.[2] The standard evaporation pan is made of galvanized iron, cylindrical in form, 48 inches in diameter and 10 inches deep. It is supported on a wooden base placed on the ground and surrounded by a woven wire fence 5 feet high. Inside the enclosure beside the pan is a rain gage and a small standard instrument, sheltered, containing thermometers. There is also provided an anemometer, placed as near as possible to the large pan so as to obtain the wind movement across the water surface.

Careful attention must be paid to the proper exposure of the apparatus so that the locality will be open to the sunshine and be representative of the weather conditions of the region. The height of the water in the pan is observed at 7 a.m. and 7 p.m., at which time readings of the other instruments are

[1] Bigelow, F. H., *Monthly Weather Review,* February, 1909, Vol. 37, p. 307.

[2] *Report of Chief of Weather Bureau,* 1914-15, p. 13; also, "Instructions for the Installation and Operation of Class A Evaporation Stations," October 16, 1915, United States Weather Bureau; also, "Current Evaporation Observations," in *Monthly Weather Review,* December, 1916, Vol. 44, pp. 647-677, illustrated.

Plate III. A.

Tower of United States Weather Bureau, carrying evaporation pans, near Salton Sea, California.

Plate III. B.

Towers in Salton Sea, California, supporting evaporation pans; view looking west, Salt Creek bridges in foreground; Towers Nos. 2, 3, and 4 in Salton Sea.

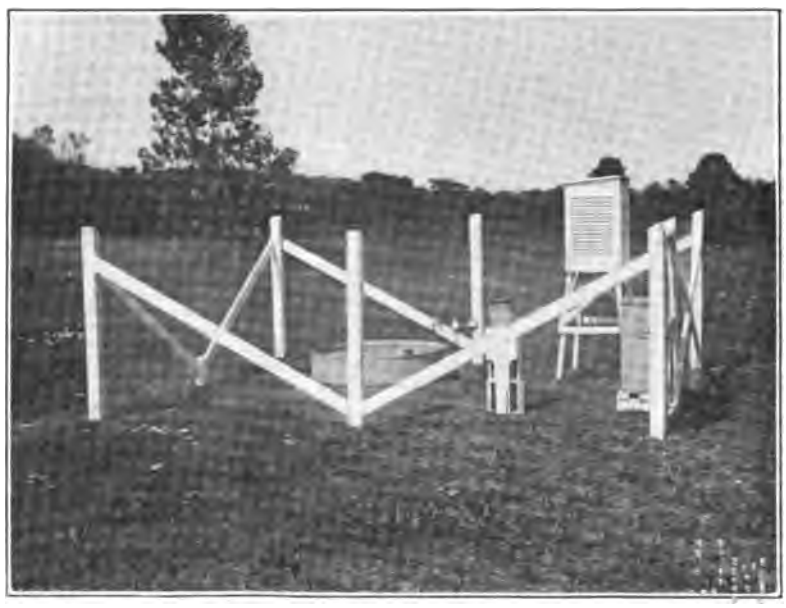


Plate III. C.

Standard Evaporation Station, United States Weather Bureau.

taken. The pan is filled with water to within two inches of the top and refilled when the water has receded one inch.

The total amount of evaporation from a reservoir or other free water surface is greatest during the hot months of the year and least in winter. During July, August, and September, if there is any considerable wind movement, the evaporation may be from a quarter of an inch to nearly half an inch a day, while during the prevalence of cold, still weather in winter the depth of evaporation from the water or frozen surface may be one-hundredth of an inch. The total for the year in northern climates may be stated in round numbers as from 3 to 4 feet in depth, while in the southern part of arid regions of the United States the annual evaporation may be 7 to 8 feet or more.

In estimates of loss from artificial lakes or storage reservoirs it is necessary to give consideration mainly to the depth of evaporation during the early summer as the storage is principally at that time. That is to say, the reservoir is filled during May and June; early in July the greatest area is usually exposed to evaporation. During the succeeding months the water is drawn down, the surface area consequently reduced and the losses become relatively insignificant. Thus it is not as important to consider the annual losses as it is to ascertain the evaporation which takes place during the time from the filling of the reservoir to the date when the surface is drawn down to its minimum area.

RESULTS. Compilations of various measurements have been prepared as noted in one of the reports on "Water Resources of Illinois."[1] As then compiled by A. H. Horton, who has freely interpolated figures for missing months, the total evaporation at different points in the United States is as given on page 72.

The evaporation from the pans placed directly on the ground is undoubtedly larger than from pans which are floating on the surface of the lake or reservoir. The figures obtained as given above are not truly representative of what is taking place from the free surface of water in a reservoir. Nevertheless, these have some value, especially as they are practically the only

[1] Horton, A. H., "Water Resources of Illinois," Report of Rivers and Lakes Commission of Illinois, 1914, Part III, pp. 306-316.

available data. Their principal use is perhaps in connection with a comparison of amount evaporated by months, the percentage for Chestnut Hill Reservoir, Mass., noted above, being as follows:

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
2.4	2.7	4.3	7.6	11.4	14.2	15.2	14.0	10.4	8.1	5.7	3.9

There is need of further research, not only in these losses but particularly into the ways or degree in which evaporation may be checked or reduced by tree planting or other devices for reducing wind movement and maintaining a lower temperature of the water surface.

ESTIMATED ANNUAL EVAPORATION

LOCALITY	DIAMETER OF PAN	DEPTH OF EVAPORATION IN INCHES
Columbus, Ohio	4′ floating	46
Birmingham, Ala.	4′ floating	51
Chestnut Hill, Mass.	4′ floating	39
Rochester, N. Y.	4′ floating	35
Dutch Flats, Neb.	4′ ground	66
Deer Flat, Idaho	3′ ground	79
North Yakima, Wash.	4′ ground	68
Hermiston, Ore.	3′ ground	68
Ady, Ore.	4′ floating	53
Brawley, Calif.	6′ ground	104
Mammoth, Calif.	6′ ground	126
Granite Reef, Ariz.	4′ ground	115

DRYING OR DEHYDRATION. Closely connected with, or growing out from, the studies of evaporation are certain practical applications of the resulting facts in the drying of bulky articles such as green wood or other raw materials and foods, in order to facilitate their transportation and storage. For example, in the case of wood, a large part of the weight of boards or timber used in construction is water. Months or years are usually required for drying or seasoning from the date the timber is cut to the time when it can be economically transported or utilized. It is obvious that great gains will come from developing ways for shortening this time of drying and for putting the material into form for use. Moreover, the process of drying out the wood frequently changes its shape, spoiling it for many operations. Recent investigations have

indicated that it is possible to dry wood rapidly under conditions such as insure the maintenance of its original form. Here research has resulted in the development of new industries.

Practically all wood before being put to use is either seasoned in the air or dried in a kiln. The main objects of such seasoning are to increase the durability of the wood in service, to prevent it from shrinking and checking, to increase its strength and stiffness, to prevent it from staining, and to decrease its weight. If drying wood were simply a matter of evaporating moisture, it would be a comparatively simple problem, since it would be merely that of supplying the necessary heat. Wood, however, has a complicated structure and unless timber that is to be air seasoned is piled in the right way, or conditions in the dry kiln are maintained according to certain physical laws, the material will probably warp or check or in some way be damaged seriously.

Until recently proper methods of seasoning have received but little attention and large losses were common. Often 25 per cent of the seasoned lumber was rendered unfit for use by defects induced by drying.

The Forest Service of the United States Department of Agriculture as stated by the Forester, Col. H. S. Graves, has conducted investigations in the kiln drying of wood for several years past and as a result methods have been developed by which lumber can be dried in months instead of years, with no loss in strength as compared to air-dried material and with very little checking or warping. The data from these investigations formed the basis of the specifications for kiln drying spruce for airplanes adopted by the Army and Navy. As the supply of air-dried spruce was exhausted soon after entering upon the war and air drying requires two years, the ability to furnish properly dried airplane material in six weeks relieved a somewhat serious situation in airplane construction. Vehicle material was generally air seasoned before the war for two or three years. The demand for vehicles for war purposes soon exhausted the air-dried stock and more was needed at once. Scientific kiln-drying methods once more came to the front and properly designed kilns were built and material dried in two

months. Runs in kilns at the Rock Island Arsenal on artillery wheel rims and spokes show losses of only 2 per cent and even less.

The drying of black walnut for gunstocks and of willow for artificial limbs are examples of other applications of kiln drying to war material where air drying was formerly the general practice, and in each case the time was reduced from years to months and an entirely satisfactory product obtained.

The main problem in kiln drying lumber is to prevent the moisture from evaporating from the surface of the pieces faster than it is brought to the surface from the interior. When this happens the surface becomes considerably drier than the interior and begins to shrink. If the difference in moisture content is sufficient, the surface portion opens up in checks.

The evaporation from the surface of wood in a kiln can be controlled to a large degree by regulating the humidity, temperature, and amount of air passing over the wood; and a correctly designed kiln, especially one for drying the more difficult woods, must be one so constructed and equipped as to insure this regulation.

Even more important in its advantages to the human race are the results which may flow from the investigations of the practicability of drying bulky foods for permanent preservation and for convenience of transportation. From earliest times mankind has largely depended for winter food upon dried meats and fruits, but the old processes of drying in the sun or by heat from a fire have usually altered the flavor and changed the food value. Recently research has shown that there are ways in which, for example, potatoes and similar vegetables may be deprived of their water or dehydrated with great shrinkage in volume and size. They can be kept for an indefinite period and then when well soaked will resume nearly their original bulk, with little loss of flavor or of food qualities.

When the fact is borne in mind that millions of tons of potatoes are transported each year and other millions of tons are wasted for lack of transportation, it can be seen that by the establishment of evaporation or dehydration plants the railroads may be relieved of hauling immense tonnage; food

can be transported and made available for the underfed or starving nations.

Dehydration methods in the United States from a commercial standpoint are still in their early stages. Much careful investigation is yet to be made, particularly as to the processes best adapted for general use, in order to realize modern ideals and meet current demands. As contrasted with the older forms of simply drying fruits and vegetables, the later methods are characterized by a treatment in which the foods to be dehydrated are subjected to the action of carefully regulated currents of air in which the temperature and humidity are both controlled within narrow limits.[1] If this is done, the food gradually loses water but without giving up its flavor or color or having its cellular structure impaired. When thus treated the product will reabsorb water, swelling to its normal size and appearance and when cooked will have essentially the flavor, appearance and odor of freshly cooked material made from fresh vegetables.

It is interesting to bring into comparison the efforts being made, on the one hand, to get water to the soil or properly to irrigate—or "hydrate"—it for crop production, as is being done by individuals, corporations, and other organizations, with, on the other hand, the efforts made later in the season to dehydrate the crops thus produced. For example, the city of Denver has not only provided water for various purposes, including gardens, but plans to dehydrate the crops or dry them so that they can be shipped or preserved indefinitely. Here are brought together the hydration or bringing in of water to obtain foods and the taking away of the excess water stored in the mature fruits.

In this connection note should be made that for every pound of dry matter produced probably five hundred pounds of water has been transpired by the plant, and that the resulting fruit consists of 80 to 90 per cent of water or from four to nine times the weight of the dehydrated substance.

[1] Prescott, S. C., and Sweet, L. D., "Commercial Dehydration: A Factor in the solution of the International Food Problem." Annals of the American Academy of Political and Social Science, Philadelphia, May, 1919.

CHAPTER V

RUN-IN

QUANTITY ABSORBED. As soon as the rain strikes the ground or the snow melts, a portion of the water, as before stated, evaporates; it "flies off" or returns to the atmosphere, while the remainder starts to flow away on the surface. Of this latter, some "runs in" or sinks into the soil, continuing to enter until the dry surface is completely saturated. The moisture travels downwards at first quite rapidly and then more and more slowly as it reaches deeper and more compact materials. In the arid areas of the country, the underlying rocks at a depth of from ten to a hundred feet or more below the surface are practically dry, although at rare intervals a heavy storm or cloudburst may cause water to penetrate to a considerable depth. In the humid parts of the country, especially in the vicinity of rivers, lakes, or swamps, the underground layers are always full of water and only the surface dries out. If a deep hole is dug through the overlying dry soil, it will finally penetrate to more and more moist rocks and then reach a point where water begins to accumulate and finally stands at a certain elevation known as the "water table." After heavy rains which soak the overlying soil, the water table slowly rises, while during times of protracted drought it gradually sinks. In arid regions a well may be drilled to a depth of a thousand feet without reaching water, but in the more humid regions the soil normally is saturated below a depth of only a few feet.

Where a natural or artificial depression like a well or drain is sufficiently deep to meet the water plane, the moisture appears on the side and collects in the form of a spring or seep. The volume of water flowing from such a spring is determined by the depth of the hole or excavation below the plane of saturation of the surrounding country and by the ease with which the

water can move through the rocks and soils to an outlet. Most natural springs are small, but there are notable examples of streams of considerable size bursting from ravines cut in the hill slopes by the erosive action of the storms.

The absorption into the soil of the water from rain or snow, its passage downward under the influence of gravity, and its storage in the ground are of great interest in connection with water conservation, partly because of the difficulty of ascertaining all of the facts. There has been more or less mystery connected with the occurrence of water underground and a tendency to a belief in the marvelous. The public has been imposed upon by the pretensions of so-called "water witches," who claim to enjoy supernatural ability to locate wells. As a matter of fact, however, these mysteries gradually disappear as the true conditions are made known concerning the behavior of water in the pervious rocks or soils.[1] The fundamental fact to be remembered is, that all of the water originally comes from the rainfall or snowfall upon some higher area, near or remote, and that it travels under the influence of gravity, always moving to the lowest level that can be reached. If the underlying rocks are gently inclined and are composed of alternating layers of different permeability, the water will gradually find its way downward and laterally along the planes of least resistance, escaping as a spring or series of springs in a deep ravine or in the bank of a river. If in the course of its travels the water becomes trapped under a higher impervious layer of rock, it may gradually acquire a head or hydrostatic pressure tending to lift the rock cover. A hole or well, drilled through this impervious cover, releases some of the water thus held under pressure and permits it to rise, possibly overflowing the surface, forming what is called an artesian well, see page 82, the name being derived from Artois, an ancient province of France where such wells were first drilled. If the casing or tubing of an artesian well is continued vertically above the ground surface, the water will rise to a point nearly level with that of the place of origin, even though this may be a hundred miles or more away. A view

[1] Ellis, Arthur J., "The Divining Rod, A History of Water Witching," U. S. G. S., Water Supply Paper No. 416, 1917.

of one of these artesian wells is shown in Pl. XVII. D, this being taken in the vicinity of Roswell, N. M., where large areas of desert land are watered by means of bore holes of this character penetrating to a water-bearing sandstone.

UNDERFLOW. In the aggregate there is a vast amount of water stored underground in the pervious sands and gravels and also in consolidated rocks. This water is usually moving slowly to points where it is escaping, the rate of movement being determined by the hydraulic head, which overcomes the resistance to flow through the interstices between the particles of rock. Under the greater part of the plains of western Kansas and Nebraska, this so-called "Underflow" has been noted. This water, passing in a broad sheet beneath the surface in a southeasterly direction, comes mainly from the rain which has fallen upon the porous soils of the high plains. It is on its way to the lower levels, where it escapes to form numerous small streams, tributary to the Arkansas, Canadian, and neighboring rivers.

The occurrence of springs in ravines on the plains and the remarkably large quantity of water which can be obtained from underground by widely separated wells has given rise to exaggerated conceptions of the vast quantity of the underflow. It has been described as a great river conveying water from the Rocky Mountains to the plains. As a matter of fact, however, the flow is an extremely slow percolation at the rate of a foot or so a day. The amount available at any one point is necessarily small because of this slow rate of delivery. Though limited in quantity, the water is of vital importance to the farmer and stock raiser on the plains. Pl. IV. A shows one of many thousands of earthen tanks. This is supplied with water by means of a windmill, such as are common on the Great Plains, which pumps from the underflow or gravel reservoir beneath the surface, lifting the water into the small pond on the surface from which it can be quickly drawn to irrigate the adjacent garden or orchard.

An illustration of the amount of water which is being pumped from underground is given in Pl. XIII. A, this showing the output of pumps near Garden City, Kan. The water is being

lifted from the coarse gravel beds which underlie the valley and, on being brought to the surface, is distributed to the fields planted for the most part in alfalfa or in sugar beets. The rate of flow has been measured at various localities, notably by Charles S. Slichter.[1] He has found the ordinary rate in the Great Plains to be about three feet a day or a mile in five years. At Garden City, Kan., where the fall of the surface of the ground is about seven feet per mile, he has measured a rate of movement of 2.5 feet per day with a maximum of 12 feet a day or less than a mile a year.

Although the rate of flow is usually not much more than a few feet a day as just noted, yet there have lately been discovered conditions in which the velocity of underground water is relatively high. Professor Slichter has measured recently in Arizona and California velocities of from 400 feet to 800 feet per 24 hours, not in especially coarse material, but in steep gradients. During 1914 he studied velocities in gravels deposited in exceedingly rapidly moving waters. These gravels are so systematically arranged with their longest axes of individual particles crosswise to the current, that the conductivity downstream is much less than the conductivity crosswise, so that the underground waters tend to dodge back and forth crosswise of the axis of the valley. Some years previously he pointed out that the conductivity of a stream-deposited gravel was different in three different directions, which he called the "axial" directions. From the results of similar work in 1885, F. H. Newell called attention to the fact that the conductivity perpendicular to the bedding was in many cases much less than the conductivity parallel to the bedding. The investigation of the three axial components in gravels deposited in rapidly

[1] For a discussion of the conditions and rates of underground movements, see the following:

King, F. H., "Principles and conditions of the movements of ground waters," 19th Report, U. S. G. S., Part 2, 1898.

Slichter, C. S., "Investigations of movements of ground waters," 19th Report, U. S. G. S., Part 2, 1898.

Slichter, C. S., "Motions of underground waters," U. S. G. S., Water Supply Paper No. 67, 1902.

Slichter, C. S., "Field measurements of rate of movement of underground water," U. S. G. S., Water Supply Paper No. 140, 1905.

moving waters is being carried on by Professor Slichter in his laboratory at Madison, Wis.

The occurrence and movement of waters which have "run in" from the surface and which may be utilized in the further development of the country have been the subject of prolonged study by the United States Geological Survey; in the following pages, Mr. N. H. Darton of that bureau, who has devoted his life largely to these matters, gives a review of the present conditions of knowledge of these phenomena—and points out incidentally the need of continued research.

Passage of Water Underground. The chief factors which control or influence the absorption of waters underground are the texture of surface material and of the rocks below and in some measure the configuration of the land and conditions of rainfall or snow melting. Absorption of water is due to the fact that most rocks are somewhat porous; notably sand and gravel can store from 5 to 15 per cent of their bulk of water. Sandstones have considerable space between their grains, but their porosity varies greatly with the size and shape of particles and with the amount of cementing material filling the interspaces; in the case of quartzite and some highly calcareous sandstones, the pores are entirely filled. Limestones are only slightly porous but they are always traversed by joints and toward the surface contain channels and caverns. Clay, shale, and slate have but very slight porosity; however, these very compact rocks are more or less broken and traversed by zones of decomposition into which surface waters descend for a greater or less distance. In many regions, also, the crystalline rocks are deeply decomposed by the solution of some of their component minerals and the resulting "rotten rock" may be as porous as sandstone. Many lavas are full of openings and in most districts they are underlain by coarse fragmental deposits.

Water passes into the ground in various ways, such as by direct inbibition of rainfall, the sinking of surface streams in passing over zones of porous rock, the spreading of streams laterally into the sandy deposits of their valleys, and the percolation of water laterally from the ocean or lakes. In all

regions it is found that the total surface run-off and evaporation are less than the volume of rainfall, thus affording evidence of general loss of water in the ground. Many streams are observed to diminish in volume or even to disappear entirely in running over areas of porous sandstone, cavernous limestone or permeable portions of their beds. In the arid regions water flows out of the mountains on rocky beds and then gradually disappears as the valley widens. Many of the great desert flats are underlain by water-bearing sands, the water being derived largely from seepages from the adjoining highlands and from transient rainfall, yet not in sufficient volume to come to the surface.

Typical Underground Water Conditions. It will appear from the above statements that there is considerable variety in the conditions of occurrence and volume of water underground. In many regions it is in broad sheets flowing slowly through permeable rocks, while in other places it is in caverns in limestone, crevices in the harder rocks, or deposits of gravel and sand. Some of it emerges again as springs in hillsides, valley bottoms and even out under the ocean—as off the east coast of Florida. In some districts, such as the enclosed desert basins, the water is in the form of an underground lake and without movement. The volume depends upon the conditions of occurrence, the water often filling or partly filling strata of considerable thickness, extending down fissures several hundred feet deep, or saturating bodies of decomposed crystalline rock.

Waters which extend widely underground are mostly contained in sandstones and some of these water bearers are of vast extent and descend to great depth. Two conditions which are typical of waters of this class are shown in Fig. 1. In the upper section a bed of sandstone receives water from rainfall or sinking of streams in the highlands at A. The water passing underground into an artesian basin has sufficient head to yield flowing wells on lower land as at B. In the second section the conditions are somewhat similar but the water escapes in springs at D, so there is a gradual diminution in pressure or head from C to D known as "hydraulic grade."

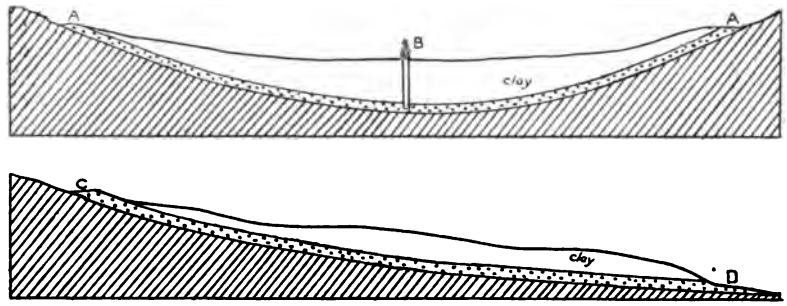


Figure 1.
Sections illustrating conditions which control formation of flowing wells or of springs.

One of the best illustrations of long-distance travel of underground water is in the central Great Plains, especially in South Dakota, where the conditions are similar to those shown in the lower section in Fig. 1. The water passes into the Dakota and associated sandstones in their elevated outcrop zone along the foot of the Black Hills and Rocky Mountains. It is carried in these sandstones under a thick cover of relatively impermeable shale or clay and escapes slowly in springs in an eastern outcrop area 4,000 feet lower. In the intervening 200 miles the water is tapped by many artesian wells which yield large flows and have pressures up to 200 pounds per square inch—the latter unquestionably indicating the connection with the highland source to the west. In valleys there is in general a flow from the sides to the center along the lines of greatest declivity and also more or less movement down the center of the valley. In the vicinity of Deming, N. M., the underflow of the Mimbres River passes under the desert flat along an old course deserted some time ago.

In the case of granites and other crystalline rocks the underground water problem presents peculiar conditions which are difficult to study. Ordinarily such rocks are not underlaid by a porous stratum and are too compact to carry any water supply. Others, however, are broken by joint planes and occasionally deeply disintegrated so that more or less water is

stored in their upper portions. Some of the crevices extend for long distances and in certain localities pass under clays or other confining deposits in lower lands so that "head" is established and they may yield an artesian flow. The occurrence of water in crystalline rocks is generally difficult for the geologist to predict, but in some places the rock structure is so evident that it may guide to a successful forecast.

Quantity of Water. The volume of water obtainable from underground sources is exceedingly variable in different regions, and in some places within short distances. In the larger artesian basins where the water is contained in thick beds of sandstone the volume is not only large but in general uniform under wide areas. In the basin in eastern South Dakota, for example, there are many wells that yield from 300 to 500 gallons a minute (0.8 to 1.3 second-feet) and a few large wells flow from 2,000 to 4,000 gallons a minute (4.4 to 9 second-feet). The area in which this condition prevails occupies many square miles, and in the aggregate there is a large volume of water flowing from these wells. The water has been used for irrigation, but its greatest value has been for municipal and domestic supply. In the Roswell district in the Pecos Valley, N. M., the larger wells yield from 500 to 700 gallons a minute (1.3 to nearly 2 second-feet), and a few of them have yielded more than 1,500 gallons (nearly 4 second-feet), but apparently the volume and pressure have diminished considerably in the past few years.

Quality of Water. Underground waters vary as much in quality as in quantity and in some cases in as short distances, but in general they are of a high degree of purity and when protected from surface contamination, they are free from disease germs and therefore highly advantageous. Some of them are mineralized from contact with rocks and minerals, ordinarily more so than are surface waters. This is because of the vastly longer time of contact, for time is an important factor in mineral solution; pressure and high temperature also act in some cases. Accordingly waters which come from salt-bearing deposits are saline, those from the gypsiferous strata contain much calcium sulphate, those from limestones are "hard" or

more or less saturated with calcium carbonate, while iron, magnesium, and many other mineral constituents occur in various proportions.

Sandstones, sand, and gravel are the materials most favorable for the storage of underground waters and as these mostly contain but little soluble mineral, the waters derived from them are of notable purity. An excellent instance of this is the group of wells 100 to 300 feet deep in eastern South Carolina, some of which yield water in which the total solid matter ranges from only 20 to 63 parts per million. In the West the proportions are generally higher; a notably pure water at Deming, N. M., from wells 85 to 240 feet deep, contains only from 224 to 240 parts per million of solid matter (13 to 14 grains to the gallon).

In places where there are flows at various depths, the qualities generally differ; for instance, in South Dakota the lower flows which are sought because they are larger in volume and contain much more mineral than the upper flows. In sinking the deep boring at Edgemont, S. D., considerable water found in the red beds was high in mineral content but the main flow from the lower sandstone was found to be of satisfactory quality after the higher flows had been cased off.

Search for Underground Water. In the extension of settlement, especially in the western United States, water supply for domestic and stock use is an all-important consideration. In some districts the pioneers have found that a satisfactory supply is obtainable, but there are many places where settlers have established themselves and then been disappointed in securing sufficient water. For wide areas few data are available or the preliminary test wells have been unsatisfactory. In most of these localities the determination of prospects for underground water is a subject requiring geological investigation, for the problem of water supply is one which necessitates study by a geologist, especially if it concerns the prospects for artesian flow, also questions of permanence and of similar features. As the water is contained in sand, sandstones and various other rocks which are included in the succession of strata constituting the earth's crust, the relations of water-

bearing beds are similar to those of coal beds and other formations. In many areas the water-bearing stratum is carried to great depths by downward dips of monoclines or basins and it may be overlaid by strata presenting considerable stratigraphic complexity. Locally it may be cut off by faults and igneous masses or affected by metamorphism and other variations in texture, especially in changes in fineness and coarseness of the sediments.

The study of such problems often requires the determination of geologic conditions and structure in adjoining areas because the evidence may be widely scattered and much of it far distant from the place where the water is desired. Considerable information is also required as to the topographic conditions or at least as to the altitude of the land where the question of head and delimitation of flow area have to be considered. The collection of data of wells already in existence is an important branch of this research because facts as to position and character of water-bearing strata, height of water in wells, or pressure if wells are flowing, and quality of water, throw much light on prospects in adjoining areas.

The determination of depths to artesian waters contained in stratified rocks sometimes can be made readily, but in many districts prediction must be based on careful examination of the local geologic conditions. The principal basis is knowledge of the thickness of the strata, and while for some regions such facts are already available, in others it is necessary to trace the strata to their surface outcrops, which are often miles from the locality in question. The structure, or dips and possible faults of the strata in the intervening country, also has to be carefully considered. The records of borings in the neighborhood may throw important light on underground relations, although in most cases the records of drillings or "logs" are so poorly kept that they are misleading; great care must be used in identifying the strata penetrated. Samples of the borings are much more valuable, especially if they have been carefully collected and labeled. An illustration of conditions controlling certain artesian conditions in a region such as the Central Great Plains is shown in the following section:

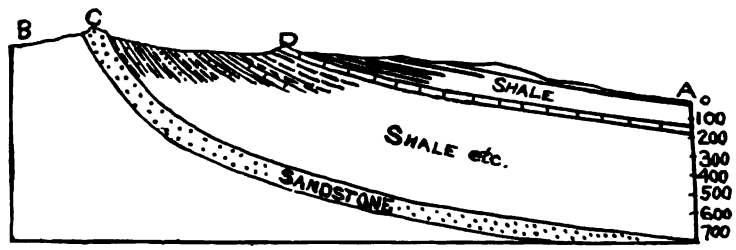


Figure 2.

Profile showing factors indicating depth to water-bearing stratum at a given locality.

Suppose that a boring is desired at A. The geologist, from an examination of the country from A to B, which may be a distance of many miles, concludes that the only promising water-bearing formation is the stratum outcropping at C. By carefully measuring the dips of the many strata outcropping from C to A, especially if aided by a distinct bed as at D, he can construct a cross section such as the one given in the figure. On this section, for example, he can base a prediction that at A the top of the water-bearing bed may be expected at a depth of 700 feet, providing the strata do not thicken or thin materially in the distance. An interesting illustration of such a prediction is at Edegmont, S. D., where N. H. Darton estimated that the water-bearing sandstone would be found at a depth of about 3,000 feet. In verification of this prediction, the Chicago, Burlington & Quincy Railroad well struck it at 2,965 feet, and obtained a large flow.

The determination of prospects for artesian flows may require extensive investigation not only of geologic conditions but of topography also unless data are already available along these lines. The consideration of head and its grade is an important factor in ascertaining the areas in which artesian flow is to be expected. In many regions of ridges and valleys flows are obtainable in the low lands, but the water must be pumped to the surface of the higher lands. If the head were level there would be no difficulty in predicting the altitude at which flowing water is obtainable, but when there is a slope or "hydraulic

grade" due to leakage, as shown in Figs. 3 and 4, careful consideration must be given to the configuration of the land.

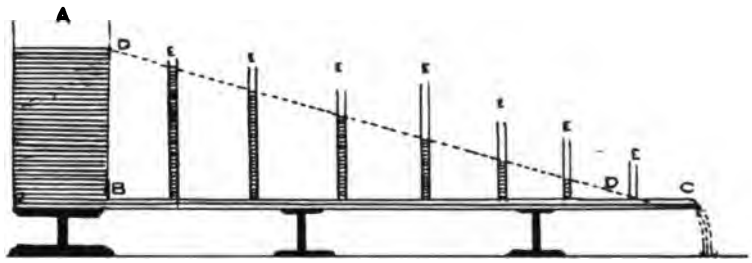


Figure 3.

Apparatus illustrating loss of head or hydraulic grade due to leakage.

The outflow at C causes the water to fall in outlets E, E, E, below the level of A. The dotted line D-D indicates the hydraulic grade. If C is closed, this line D-D will tend to become more nearly horizontal from A.

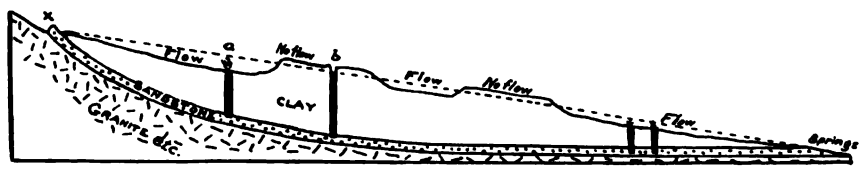


Figure 4.

Profile indicating conditions of success or failure of artesian wells.

The sandstone resting on granite, as indicated in above figure, receives water at X; some of this ultimately escapes in springs in the valley bottom. A well drilled at *a*, being below the hydraulic grade,—which is indicated by the dotted line,—will flow, while one at *b* will not.

The conditions in central South Dakota furnish an excellent illustration of an investigation of prospects for flows in parts of a broad artesian basin. As explained above, the water enters the sandstone in its outcrop zone in the Black Hills and finally leaks out in springs where this sandstone comes to or near the surface 200 miles east, in lands about 4,000 feet lower. The water is held down in the intervening district by a thick body of shale which is nearly impermeable; where the water-bearing bed is reached by deep wells high pressures are found. If it

were not for the outflow to the east and possibly some slight general leakage, the pressure would be greater and the flow area larger, because the initial head is equal to an altitude of 4,000 feet or more. As it is, a "hydraulic grade" is sustained by the great friction of the water in its slow flow through the small interstices of the sandstone. Owing to this grade the head falls below the altitude of the land in many parts of the district and accordingly the flow area is considerably restricted.

Some of the negative features of underground water prediction are of great importance. In many localities it is evident from the geologic conditions that no water supply, or at least no artesian flow, can be obtained; in such places it is possible to avoid the great waste of expense of deep boring which cannot succeed. This condition is occasionally evident from the surface geologic facts or may be inferred from the samples of borings after certain beds have been penetrated. There are frequent instances of deep borings made in compact granites or other crystalline rocks which a geologist of experience knows cannot contain water, or in shales which are so thick that underlying strata cannot be reached by the means available. It is probable that in the aggregate the warnings against hopeless borings have been even more valuable than the predictions that water would be found. These warnings have saved the waste of large amounts of money, but sometimes they will not deter the driller who has some theory of his own which he believes is of greater value than the scientific deductions of the geologist. On the other hand also, boring has been discontinued in many places where the geologist knows that at greater depth there is almost a certainty of obtaining flowing water or a supply that can be pumped.

Conservation of Underground Waters. As the reservoirs of artesian and other underground waters are not of unlimited capacity, depletion is sure to follow excessive draft and long-continued waste. The general head of the artesian water inevitably decreases when the outflow is in excess of the intake; locally the head is sensitive to the drain of many flowing wells near together because the underground movement of water is so slow. Time is an important factor in sustaining the outflow

when there are many outlets in a restricted area. Generally a flowing well is more valuable to the user than one from which the water has to be pumped, so that when flow ceases and pumping is necessary the well passes into a different category—especially as the available volume of water usually diminishes at the same time.

The effect of vigorous pumping of adjoining wells in diminishing or stopping flow and in reducing the water level in pump wells is frequently observed and raises an important question of equity. There are many localities at which flows were originally obtainable where now the head has been so diminished that pumping is necessary. A notable instance is Denver, Colo., where twenty years ago the head was sufficient to afford flows at moderate heights throughout the city while now the water must be pumped and the volume is much less. This is caused by the multiplicity of wells from which water is pumped faster than it comes in at the intake zone.

Another notable example is the Pecos Valley artesian area about Roswell, N. M., where the amount of water and width of flow area have been steadily diminishing. Still another is in southern California, where heavy draft for orchard irrigation caused many wells to stop flowing accompanied by diminution of the area of artesian flow. Fortunately this overdraft has been restricted somewhat and an attempt is now made to keep the water level uniform. Such restrictions for the perpetuation of supply are all important, for when the amount of water available diminishes, irrigation projects are impaired and settlement is retarded. This is especially deplorable where the water has been permitted to run to waste as in Pecos Valley and other regions. In South Dakota and some other states, laws have been passed imposing fines for waste of underground water.

For many years geologists employed by the federal government have been investigating underground water prospects, as well as all other water resources in many parts the United States, and several of the State Surveys have conducted local investigations. It is now universally recognized that these problems of development and use of supplies are mainly geological; a knowledge of structural relations, rock characters and other

allied features are the main factors for consideration. The work in the United States Geological Survey was inaugurated in 1894 and it has since continued without interruption. Many reports have been published affording a vast number of data in various portions of the country. However, a great area still remains to be investigated and many parts of areas already examined are yet to be tested by deep borings before their capabilities can be definitely known.

The subsoil water has been studied particularly by the Bureau of Soils of the Department of Agriculture. One of the most suggestive results is the bulletin[1] prepared by Dr. W J McGee who conducted inquiries as to the height of the ground water throughout the United States. His data indicate that there has been a lowering of subsoil water level of about 3.5 feet per decade; in the older states the average lowering since settlement appears to be not less than 9 feet. This is presumably the result of the cutting off of the source of supply; the storm waters rush off in floods instead of passing into the soil. This waste is in part preventable. The public welfare demands that efforts be made to continue the acquisition of data and the enlargement of general knowledge so that steps may be taken to conserve the ground water and to prevent flood waste which impoverishes the soil and impairs the value of the larger waterways as sources of water supply and for power and navigation.

[1] McGee, W J, "Wells and Subsoil Water," U. S. Department of Agriculture, Bureau of Soils, Bulletin No. 92, 1913.

Plate IV. A.

Small earth reservoirs or tanks for storage of water pumped by windmills from so-called underflow, Garden City, Kansas.

Plate IV. B.

Storage in mountains. Jackson Lake at head of Snake River, Idaho-Wyoming.

Plate IV. C.
Brush wing dams to prevent erosion of levees, near Yuma, Arizona.

Plate IV. D.
Sedimentation, adding silt to clear water for the purpose of reducing seepage from a canal, Minidoka Project, Idaho.

CHAPTER VI

RUN-OFF

The term "run-off" has come into common use to designate the water which flows from the surface of the ground in rills, uniting to form brooks, creeks, and rivers. It is that part of the rain- or snowfall which remains after a portion—the "fly-off"—has been evaporated and another part—the "run-in"—has been lost by soaking into the ground.

The question as to the relation between the rainfall and the run-off is one which has been frequently discussed. Many efforts have been made to express the run-off as a percentage or ratio of the rainfall. These have not been successful because of the fact—as noted on page 66—that the run-off is not properly a fixed or definite proportion of the rainfall. On the contrary it is the surplus or remainder after absorption and evaporation each has had its share. It thus happens frequently in the drier regions or at times of drought in humid climates, that all of the rain which falls in a light shower is evaporated even before it touches the earth (see page 55), or it may disappear into the soil without giving any visible run-off.

Taking any one locality, however, it is often possible to state the average run-off and from this draw useful conclusions as to what may happen in this and similar localities. For example, in some parts of New England where the measurements of rainfall and of run-off have been continued for many years, it has been found that ordinarily about one-half of the rainfall appears in the rivers flowing to the ocean. As we go west from New England, it is found that the run-off decreases more rapidly than does the average rainfall, so that in the Middle West we may say that from 20 to 25 per cent of the rainfall appears as run-off.

When the annual rainfall drops as low as 15 to 20 inches and arid conditions prevail, the run-off becomes proportionately far less—down to 5 per cent or less of the precipitation. In the country west of the Rocky Mountain region is an area known as the Great Basin from which there is no run-off. The rivers which rise in the forested slopes of the mountains flow out from these into the lower valleys where their waters disappear completely and the streams, never reaching the ocean or large lake, are described as "lost rivers." In former geological ages these interior basins are known to have been filled to the point of overflow, but within the historic period the level of the lakes or marshes into which these lost rivers disappear is several hundred feet below the point where the water formerly escaped on its way to the sea.

The character of the topography necessarily has a direct influence upon the quantity of run-off, for if the rain falls upon a flat surface from which it can flow away only after the lapse of an appreciable time, a much greater portion will sink into the ground or will be lost by evaporation, as noted on pages 66 and 76, than would be the case if the rain fell upon steep slopes and was immediately concentrated in rivulets or torrents. Thus the run-off from hilly or mountainous country must obviously be more rapid and in greater proportion than the run-off from the plains or prairies. A classification of lands by topographical conditions and as regards run-off has been found convenient because of this fact and also because of the related condition that the elevated or mountainous region usually receives heavier and more nearly continuous precipitation than the plains.

One of the earliest attempts to indicate the relation which exists between topography, rainfall, and run-off is that given in the fourteenth Annual Report of the United States Geological Survey, Part II, in what has since been named the Newell curve. There is also given a map of the mean annual rainfall and one of the mean annual run-off, the diagram serving to connect in a general way the relation which exists between these two maps.

Any estimate of the probable flow based upon a study of rainfall data is liable to large errors—therefore most engineers

have reached the conclusion that it is safer to depend upon direct measurements of the run-off, if such are available, and to base their conclusions upon their measurements rather than upon inferences drawn from the available records of the time and quantity of the rain. Thus, although the measurements of precipitation should be continued and extended, it is evidently of equal or greater importance, in considering reclamation projects or systems of water storage, to make as many direct measurements as possible of the amount of water which actually occurs in the streams at important points day by day and year by year. Observations carried on through a series of years show that the run-off on any stream fluctuates more widely even than the rainfall.

Systematic research and collection of data on stream flow was begun by the United States Geological Survey in 1888, primarily for ascertaining the extent to which the arid lands of the western part of the country might be reclaimed by irrigation.[1] Later the observations and measurements were gradually extended throughout the eastern states, furnishing information needed by engineers and investors in connection with water power development, drainage and flood protection. Gagings or measurements of the rate of flow at different heights of water have been made on many hundred rivers, large and small. From these data, computations have been made of the average flow through seasons or years—also of the greatest floods and droughts. Most of these estimates extend over only a few years—but for some important localities facts are now available showing the fluctuations on river discharge for a quarter of a century.

In looking over the results of stream measurements, the most striking feature is the great variation in run-off between the eastern and western rivers, the difference being entirely out of proportion to the difference in rainfall in the two areas. Comparing, for example, the Susquehanna River of Pennsylvania,

[1] Newell, F. H., "Result of Stream Measurement," 14th Annual Report, U. S. G. S., Part II, pp. 95-155.

Also, "Methods and Results of Stream Measurements by U. S. G. S.," *Proceedings Engineers' Club*, Philadelphia, Vol. XII, July, 1895.

having a drainage of over 24,000 square miles, with the Rio Grande of New Mexico, with a drainage area of 30,000 square miles, it is found that the average run-off of the Susquehanna is 30 times as great although the rainfall on the basin is probably not more than three times as heavy.

The average flow per square mile drained is usually less for the larger drainage basins—the outflow from which has been measured—than from the smaller; or to put it in another way, the headwater tributaries discharge more water per square mile of area from which this water flows than does the main stream lower down. This loss is due to evaporation, and seepage, or the discrepancy may arise from the facts that the rainfall is not as uniformly distributed nor as general over the larger tributary country as on the smaller possibly more mountainous area.

For the eastern part of the United States, where the rainfall in general is from 30 to 40 inches in depth, the yearly run-off is from 1.2 to 1.8 second-feet per square mile, while in the less humid country it may drop, as in the case of the Rio Grande and Colorado rivers of the West, to 0.01 or less second-feet per square mile. In wet years the average flow may be double that of the ordinary run-off and in times of drought the flow may nearly or completely cease. Taking a dry year, the total discharge is usually not less than half the average flow for a decade.

Especial emphasis should be placed on the fact that the losses by evaporation which take place, to a large extent, are constant, regardless of the location, the chief differences depending upon the length of the growing season. These losses range from 19 to 28 inches; unless the rainfall exceeds this amount there will be practically no run-off, except floods due to excessive precipitation. This fact is illustrated by plates 9 and 10 in the fourth edition of Hoyt and Grover's "River Discharge," helping to explain the wide difference in run-off from eastern and western areas.

It is important to keep in mind the fact that during the growing period the losses amount to about $3\frac{1}{3}$ inches per month. The losses during other periods will amount to about 5 inches; therefore, in an area where the growing season is six months, a

loss may be expected of about 25 inches, or with a 50-inch rainfall, there should be about 25 inches of run-off.

During the days of greatest flood the rivers of the Atlantic Coast may discharge for several hours at a time at a rate of from 20 to 50 second-feet for each square mile of drainage basin. In comparison with these, the western streams in flood rarely contain more than one-tenth of this quantity.

Floods and Drought. The extremes of river flow are among the causes of some of the great catastrophes to which humanity is subjected; great floods destroying lives and property have occurred in all ages and in all countries. During the present decade the annual and often preventable losses in the United States amount to many millions of dollars. The earliest legends of many nations of antiquity refer to some great flood or deluge which practically wiped out the majority of the people then living, only a few persons surviving to perpetuate the race; the impression made upon the human mind testifies to the overwhelming damage wrought.

On the other extreme are the droughts which, while less striking in their immediate catastrophic effect, have had far-reaching result in forcing the migration of tribes or of nations and in thus producing great movements of humanity in which wave after wave of barbarians from the more desert places have been driven into Europe and have made history. While some floods or droughts have been the immediate result of an unusually large or small rainfall, yet many have come from the cumulative effect of small differences of precipitation, their effect being greatly magnified by the accompanying conditions of heat and wind movement. Conversely, widespread droughts have accompanied a relatively small diminution in rain. A drought has been defined for purposes of study as a period of time during which in less than ten days there has fallen 0.10 inch of rain or less; or in less than 20 days, 0.20 inch or less; or in 30 days not exceeding 0.30 inch of rain.

Insurance against flood on the one hand and against drought on the other, is among the most important undertakings of mankind. The necessity of such projects is now being appreciated as never before. Theoretically it should be easy to hold

over the excess of water from one time and place for use in another. Practically this is extremely difficult and requires for success the solution of many engineering and social problems, as will be discussed on later pages. The storage of water in large quantities is not always practicable; for safety against flood damage there must usually be joined some form of protective work as distinguished from the preventive effects dependent solely upon holding back the floods in reservoirs. This subject is discussed on page 272 under the head of river regulation.

During floods most of the work done by rivers is accomplished. At that time the erosive effect is greatly increased. Vast quantities of silt, sand, and gravel are picked up and deposited at more or less distant points. The rapid increase in volume of the stream causes correspondingly quick changes in erosion and deposition or sedimentation. The lower plains along the river are inundated and their level gradually built up by the sand or mud dropped by the encroaching water. As these flood plains are thus made of light and fertile soil, they are usually first occupied by the pioneers in a new country and later are thickly built upon by the inhabitants. The occasional flood waters, and especially those of unusual floods spreading over their old playgrounds, thus become highly destructive to the community which has taken possession.

As the result of the great losses of life and property due to floods on these lowlands, various investigations have been made to ascertain how best to meet future dangers. The most notable of these studies and the ones which have led to early action, are those which followed the March, 1913, flood in the Miami River of Ohio. This river and its tributaries became filled to overflowing by what may be termed an accidental coincidence during five days of not very extraordinary rains. The waters spread out over the river bottoms, which had been gradually built upon and occupied in large part by towns, factories and railroads. The loss of life directly and indirectly was over 400 and the destruction of property exceeded $60,000,000. The larger cities damaged were Dayton, Hamilton, and Piqua. A study of the situation was at once undertaken and under an act passed by the Ohio Legislature, the Miami Conservancy Dis-

trict was organized.[1] Work has been begun on six large detention reservoirs, the capacity of which is sufficient to hold back a large portion of the flood flow, enough to prevent the waters from breaking over the protecting works built through the principal cities.

The city of Columbus, Ohio, also suffered from floods, which began on March 24, 1913, during which nearly 100 lives were lost, suffering was brought to 20,000 persons, and property destroyed valued at over $5,000,000.[2] The city authorities, after having had reports prepared on various schemes of relief, have concluded that the cost of establishing reservoirs on the Scioto and Olentangy rivers would be too great and have therefore confined their efforts to the straightening and deepening of the river channel and to the building of protective works through the city.

The floods which partly inundated the city of Pittsburgh during the period from March 15, 1907, to March 20, 1908, caused losses[3] estimated at over $6,000,000. A flood commission was organized in 1908, extensive investigations were at once begun and carried on by means of an expenditure of upwards of $100,000. These have resulted in a remarkably complete report, which goes into methods of flood prevention and control, also recommends the building of large reservoirs on the headwaters of Allegheny River. Little has apparently come out of this report, other than a better comprehension of the whole subject.

Erosion. During a downpour, the raindrops as they strike the earth loosen the particles of soil and in a heavy shower even move pebbles. A very small part of the soil enters into solution in the pure rain water, but a larger portion is mechanically held in suspension by the water as it flows off in muddy rills. As these rills unite in swiftly moving torrents, they push and roll along larger particles, carrying them into creeks and rivers.

[1] Morgan, Arthur E., "Report of the Chief Engineer of the Miami Conservancy District," 1916.

[2] Alvord, John W., and Burdick, Chas. B., on "Flood Protection," 1913, and "Flood Relief," 1916.

[3] Pittsburgh Flood Commission, Report, 1911, pp. 253; appendix, 452. Illustrated with diagrams, maps, and views.

Thus, following the rainstorm, we have not only an increase in the volume of flow but a muddied condition of water which testifies to the movement of earth material. As the water in the stream subsides it tends to become clearer and there are left along the streams many low beds or bars of sand or silt showing that the river water, with its diminished volume and lessened velocity, was not able to carry away all that it had picked up.

Observation reveals the fact that the power of water to erode and carry away small particles does not vary directly as its velocity. That is to say, a stream flowing twice as rapidly is not limited to twice as much material, but on the contrary, when the velocity is doubled there may be thirty or forty times as much solid matter held in suspension. Thus a slight change in the velocity of the flowing water makes a great difference as regards the load it can handle. While the water on one side of the stream may be cutting into the overhanging bank, on the opposite side, where it is moving more slowly, it may be dropping some of the load it picked up a few hundred yards above.

Studies have been made of the behavior of water in this regard. Perhaps the most elaborate have been those of G. K. Gilbert on "The Transportation of Debris by Running Water," published by the United States Geological Survey in 1914. Mr. Gilbert built small flumes, some with glass sides, in which he could observe and measure the erosive action of streams of water of known velocity. He fed into this water particles of determined size and noted the behavior of these, feeding each stream until it became clogged. He found that the load travels less rapidly than the current and that a mixture of coarse and fine particles can be more readily transported than those of single size alone. The tentative conclusions concerning the laws governing the movement are found to be conflicting but the old rule that the quantity varies as the sixth power of velocity was discovered to pertain not to the quantity of material but rather to the maximum size of the pebbles.

The prevention of erosion involves many problems of hydraulics and reaches out into various fields of engineering. Beginning with the uplands of a river basin, as stated on the previous page, it is of the highest importance to preserve a suitable cover-

ing of vegetation on the soils which are easily eroded. Proceeding down the watercourses, it becomes necessary to protect the banks from being worn away at points where the velocity is greatest. For this purpose stone is used wherever possible, but in many localities it is not practicable to obtain suitable rock. Here the protection of the banks from erosion is achieved largely by ingenious methods of placing and holding the brush or small trees which usually grow in the vicinity. An illustration of one of the methods of protecting soft banks from erosion is shown in Plate IV. C, consisting of wing dams of brush built to extend out from the levees along Colorado River below Yuma, Ariz.

The use of brush in the form shown in the illustration or woven into mattresses has been brought to a high degree of perfection; willows, cottonwoods, and other small trees have been utilized to a degree such that the material for building the mattresses has been largely consumed and it is becoming quite difficult and expensive to secure an adequate supply. Under these conditions a substitute has been sought in the application of concrete. (*Engineering News*, December 7, 1916, p. 1094.) There is need of continued study and research—to be followed by the use of inventive genius—into the factors which control the erosion and transportation of earth or rock particles and into the mechanical devices for economically maintaining the banks of the rivers subject to destructive floods.

Sedimentation. The deposit of sediment which has been eroded from the land higher up on the stream may be a benefit or an injury. Primarily, nearly all of the rich lowlands have been formed in this way. Along the rivers of antiquity, the Nile and the Euphrates, all agriculture and even civilization itself came from these river deposits. After a flood subsides the slime or sand left on the flood plain utilized for farms or other industries is apt, in a humid country, to be more of a detriment or nuisance than a benefit. There are conditions, even here, however, when sedimentation can be turned to useful ends. By controlling the access of muddy water to low-lying lands it has been found possible, for example, in England to build up the

level of the land by a process known as "warping" and to produce fields of great fertility.

Another practical use of the silt carried by rapidly flowing water is in vogue in the arid region. There where canals and ditches have been built for many miles through sandy soils, much of the water, if clear, is lost in transit during the first few months or seasons after the canal is dug because of the rapid percolation into the porous bed of the canal. The water thus disappearing may later reappear in the form of seepage to the injury of low-lying farm lands. To prevent such seepage, efforts are made to seal up the bottom of the canals by bringing in muddy water or by making muddy the natural clear water by the addition of clay. Such an effort is shown in Pl. IV. D, where silt is being added to the clear water of canals taken from Snake River. This is being conducted through many miles of canals built in the sandy Minidoka Project in southern Idaho. The losses from these canals have been a serious matter in that the water is not only needed elsewhere but, escaping from the canals, has ruined many otherwise good agricultural lands.

As shown in the view, the muddy water is being brought in a flume from which it spills into the clear water of the canal and is swept along downstream. The particles slowly settle to the bottom of the canal, forming a thin coating of slime, and gradually work their way between the sand particles, plugging up the pores and reducing the water loss. (See also page 218.) The success attained here should stimulate additional research into the law governing such phenomena.

Debris Problems. In certain portions of the country there are special problems closely connected with erosion and sedimentation following flood conditions. In particular, in California, the debris which has resulted from hydraulic mining has introduced situations peculiarly difficult. Here man in his efforts to secure gold has disturbed the otherwise stable conditions and has initiated changes which have led to widespread injury. The ancient sands and gravels in the upper mountain valleys which have remained in place for ages have been moved by the hydraulic "giants" of the miners and left in such position that the occasional floods are able to sweep them down over

the lowlands, choking up the streams and encroaching upon thousands of acres of land formerly valuable for agriculture. Here is thus presented an important series of questions intimately connected with the development of the waters and other mineral resources of the country. The research conducted by Dr. G. K. Gilbert, noted on page 98, was undertaken largely with a view to aiding in the solution of some of these engineering problems, where the economical conduct of one operation—that of mining—has resulted in great losses to agriculture. By obtaining more complete knowledge it is possible that a satisfactory adjustment may be worked out.

Varying Quantities. The measurement of the amount of water which flows in the principal streams and the resulting data form the foundation upon which are based most of the plans and estimates for investment of public or private funds in projects for irrigation, drainage, hydraulic power and river control. The quantity available for use for storage fluctuates greatly from day to day and from season to season. The engineer in preparing his plans must act the part of a prophet; he must anticipate conditions which will exist not merely tomorrow but next year and for many years. The question is as to how he can safely make these long-range predictions.

The permanence of natural phenomena is the foundation on which the engineer builds. He assumes not only that the seasons will follow in order as they have always done, but that the supplies of water will fluctuate about as they have in the past and within about the same limits. This being the case, the obvious thing to be done is to ascertain, if practicable, what has happened in the past, what is taking place now, and especially what are the limits of quantity of flow of the streams at different times and places. The more complete is this knowledge of past and present stream behavior, the stronger may be our reliance upon the anticipation for the future.

It has been shown on previous pages that the amount of water running off the land is the resultant of many forces each acting more or less independently. We can imagine an extraordinarily heavy rain culminating in a series of great storms, in which all of the natural conditions for producing a flood are at their

maximum. Such conditions may appear once in twenty years or once in a century, but the probabilities of their occurring in any one year are small. On the other hand, we can take the mimimum condition of rainfall with maximum wind movement and temperature occurring in such a way as to produce extraordinary droughts. The probabilities also of these occurring in any one season are small. If we have records for a century or even for several centuries and find that neither of the theoretical extremes has been reached, we are reasonably safe in limiting our computations to what has actually occurred. More than this, it has become apparent through studies of the few available long records that the extremes of flood and drought are usually to be found in a period of less than fifty years. When still shorter periods are taken, however, there can be less and less confidence in using these as giving the limiting conditions in our estimates for the future.

Data Available. It is obviously not practicable to wait for half a century or even for a decade to obtain data on river flow in order to prepare computations for projects of hydraulic power or for works for conservation of water by storage. If these are to be built for municipal supply, for irrigation, or for industrial development, it is usually necessary that work be begun within a few months from the time it is actually determined upon. The moment it becomes evident that such enterprise is practicable, steps should be taken to make measurements of the flow of the streams which are to be utilized, ascertaining first what observations may have already been made, preparatory to supplementing these.

Fortunately certain governmental agencies, national and state, directed by men of wide vision, have anticipated some of these future needs and have entered upon research designed to meet the demands which are likely to be made as the resources of the country are developed. The most notable of these undertakings has been that of the United States Geological Survey, initiated under Major John W. Powell, which began in 1888 to ascertain the extent to which the arid regions might be reclaimed. In this work has been included the preparation of topographic maps of the catchment basins of the streams and also of prob-

able reservoir sites, as well as of measurements of the streams. This latter research into water supply was extended to the eastern states to furnish data needed in considering possible water power development, river control, drainage and other needs. Coöperation in these investigations has been had with other bureaus of the government and with some of the states, so that there are now available data concerning many of the important streams. The facts at hand, however, are by no means adequate to answer all of the questions which occur to the engineer, investor, or man interested in public affairs. There is need of extending these studies and of taking up even more thorough research in connection with special problems.

When the systematic work of stream measurement was initiated in 1888 there were few instruments for river measurement and no general understanding as to the kind of facts to be collected or the way in which these should be preserved and presented. In the thirty years which have elapsed there have been developed certain more or less arbitrary ways of procedure, these having been modified from time to time to meet the needs of the engineers.[1]

It is generally agreed that the data most readily obtained and which have greatest value are those as to the amount of water which passes a certain selected point near which the water is to be used or stored. The choice of point of measurement is governed not only by the use to which the facts are to be put, but also by the surrounding conditions which affect the accuracy of the result. Often it happens that because of obstruction in the stream, measurements cannot be made at the desired point and can be satisfactorily had only at locations some distance above or below.

Computations of the flow of a stream and of its diurnal or seasonal fluctuations are usually based on systematic observations of the height of the water. It is generally assumed that with increase of quantity the river surface will rise and with decrease it will fall. The principal exceptions to this rule are those which arise from the gradual filling up or the erosion of

[1] Hoyt, J. C., and Grover, N. C., "River Discharge," several editions, illustrated.

the bed of the stream or by temporary obstructions such as ice jams. Also it is assumed that as the river rises it will flow more rapidly and as it goes down the speed will decrease. The quantity or rate of flow is determined by ascertaining the vertical area or cross section of the stream taken at right angles to its line of flow and by multiplying this area by the speed with which the water passes. If the ordinary British units are used, the results of the flow will be stated in cubic feet per second. A stream having a width of 100 feet and an average depth of 5 feet will have a cross section of 500 square feet. If the water passes this cross section at the rate of 2 linear feet per second of time then the stream will be flowing at the rate of 1,000 cubic feet per second, abbreviated to second-feet or even to cusecs.

The cross section of the stream can be obtained by direct measurement of its width by a suitable steel tape or chain and of its depth by sounding with a pole or other device. The ascertaining of the velocity of flow, however, is not such a simple matter because of the fact that the water is not moving with the same velocity in the center and at the sides, or at the top and bottom. It is moving most swiftly near the center a little below the surface and is nearly motionless near the sides or may even have a return eddy on the margin. To make measurements of discharge, it is evident that a suitable cross section should be chosen where the water, undisturbed by obstacles, is moving as quietly and in as nearly a straight course as possible. Such places are difficult to find and usually choice must be made of the locality offering the fewest objectionable features. The river channel usually offers an alternation of broad shallow places where water is rippling over the stones, which below this may be a deep pool with more or less dead water at the bottom.

Units of Water Measurement. In discussing the quantity of water which occurs in the streams or which may be held by storage and measured out for various purposes, different units are employed. The metric system is in quite general use, but unfortunately in English-speaking countries adherence is still had to the old system of measurements—the gallon[1] being habit-

[1] There are two gallons in common use, the standard United States

ually employed, for example, in domestic and municipal supply, and the cubic foot for other purposes. Considering still larger volumes of water, particularly in connection with the irrigation of agricultural lands, the acre-foot is employed, that is, the quantity of water which will cover one acre, or 43,560 square feet, to a depth of one foot.

A stream discharging one cubic foot of water per second will in the course of a day of 24 hours (60 x 60 x 24) discharge 86,400 cubic feet or very nearly 2 acre-feet (1.98). Thus there is a convenient connection in that a stream of this size flowing continuously delivers very nearly 2 acre-feet per day. The cubic contents of a reservoir, if stated in acre-feet, can be readily converted to a rate of flow, that is to say, a reservoir containing, say, 10,000 acre-feet, if drawn down at a steady rate through 100 days, would yield a flow of nearly 50 cubic feet per second; conversely, a stream which is flowing at a rate of 100 cubic feet per second through a month of thirty days will deliver 6,000 acre-feet.

In stating the quantity of the flowing water, the cubic foot per second has largely superseded the gallon. In estimates of storage capacity reservoirs, or use in city supply, the gallon still survives, though when the figures run into the millions, the term "million-gallon" has been used. In the western part of the United States, where the hydraulic miners made measurements of flow of water adapted to their needs, the so-called "miner's inch" was devised, this term being perpetuated by the irrigators, who frequently obtained water from the old hydraulic workings. The miner's inch is supposed to be the continuous flow of water issuing from an orifice of one square inch section. This quantity, however, varies widely according to the character or thickness of the plank or plate in which the opening is made and according to the height of water above the

gallon contains 231 cubic inches, or 8.34 pounds avoirdupois, of distilled water. This is almost exactly equivalent to a cylinder 7 inches in diameter and 6 inches in height. It equals 3.78 liters. The British imperial gallon, referred to in English publications, contains 10 pounds of distilled water, or 277 cubic inches, or 4.54 liters, and is almost exactly 1.2 United States gallons. The cubic foot contains 7.48 United States gallons. A cubic foot of pure water weighs 64.2 pounds and contains 28.3 liters.

opening. Thus the miner's inch, while convenient under certain conditions, is an uncertain quantity; it has been defined in some of the western states as a fiftieth part of a cubic foot per second, in other states as a fortieth part.[1]

STATION EQUIPMENT. As soon as a location for river measurement has been selected and a temporary or permanent gage has been established, the next step to be taken toward making systematic measurements is to properly equip the locality for convenience in handling the apparatus which may be used. There are various methods of making the measurements and upon the selection of one or another of the methods depend the character of the equipment and the accuracy of the result. As a rule, however, the current meter is generally employed, although occasionally surface or submerged floats are used. In handling the current meter the operations may be performed by wading into the stream, if small, or by holding it from a boat or bridge. Boats, however, are often dangerous in high water and bridges not always conveniently located, so that recourse is had to a cable suspended across the stream, from which can be hung a small box or car in which the hydrographer can sit.

The height of the water is ascertained by reading some form of gage of which there are many kinds; the most common being a vertical post marked to feet and tenths or a scale attached to a bridge pier. Where the shores are sloping, it has been found most convenient to have an inclined gage following the slope of the bank. Other schemes are also in use; in some cases a weight is lowered from a bridge until it touches the surface of the water and the distance is read downward from some fixed point. Occasionally a well or pit is dug near the river and connected with it by a horizontal pipe below low water level so that the water will rise and fall in the well with that in the river.

There are various types of automatically recording gages, many of these dependent upon the movement of a float in such a well connected with the river. As the float rises or falls it causes a pencil or pen to move across a sheet or dial driven by a clock so that the time and amount of movement can be readily

[1] Hoyt, John C., and Grover, N. C., "River Discharge," John Wiley & Sons, New York, various editions, illustrated.

Plate V. A.
Measuring flow of water in Ironstone Canal, near Montrose, Colorado.

Plate V. B.
Weir for measuring water in one of the canals of the Williston Project, North Dakota.

Plate V. C.

A plains reservoir site, that utilized for the Cold Springs Reservoir of the Umatilla Project, Oregon.

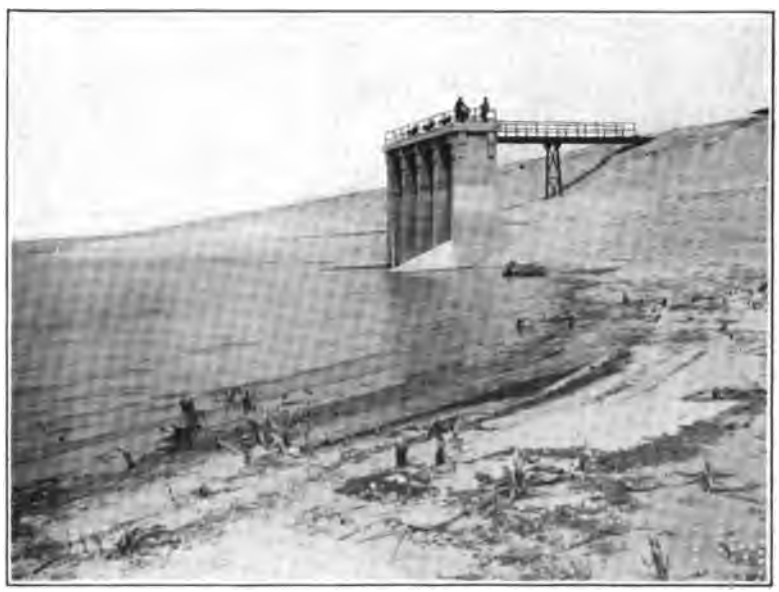


Plate V. D.

A reservoir built on the plains or open valley lands, because of lack of adequate natural storage sites in the mountains. Deer Flat Reservoir, Boise Project, Idaho.

seen. On many streams there is a distinct diurnal fluctuation in the quantity, noted by the self-recording gage, but often overlooked by the ordinary observer.

There are usually few people residing near the point where it is desired to make measurements of river flow for purposes of water storage, as these places are mainly in or near high mountains. It is thus frequently a matter of considerable difficulty to secure systematic and reliable readings at reasonable cost. Many of the observers become careless and some have been known to write up the book at the end of the week. To guard against this it is desirable to have an inspector visit the locality at irregular intervals. Frequently it becomes necessary to abandon a point because of the unreliability of gage readers, or where it is too expensive to install automatic devices.

Discharge Measurements. The most simple method of ascertaining the rate of flow of a stream is by observing the speed with which some floating object passes downstream. For example, a course along the side of the stream may be laid off with a length of 100 feet. The time of passage of a floating log may be taken from the upper to the lower end of measured course. Smaller pieces of wood or metallic floats may be used for this purpose, being placed at different distances across the stream so as to obtain the velocity near the sides as well as near the center. Inasmuch as the surface has greater velocity than the lower portion of the water, the average speed can be better determined by causing the floats to ride upright in the water by loading one end until it sinks nearly to the bottom. These vertical floats, if well placed, give nearly the average speed of the stream.

To obtain more accurate facts as to the velocity at all points, it is desirable to have an instrument which can be placed in any part of the current. Such a device is shown in Pl. V. A, this being one of the current meters in use by the Water Resource Branch of the United States Geological Survey and also by the United States Reclamation Service. This consists of a revolving head or wheel held in such a way as to turn in the moving water. The greater the speed of water the more rapid the revolutions of the wheel.

The current meter can be used in a number of ways. For example, it can be held at points systematically located across the stream near the bottom, center and top. From the average of these readings the mean velocity may be determined. The method of use depends to a large extent upon the size of the river and the device employed for getting at the stream. In very small streams it is possible to wade out in them and hold the meter in the desired location. On larger streams if there is a small bridge conveniently located, as shown in Pl. V. A, it is possible to locate the meter wherever desired and to move it from side to side as well as up and down. In working from a car or box suspended from a cable, it is less convenient to move sideways and so the method employed is usually to measure the velocity of several vertical sections and to compute the discharge of each independently of the others.

The engineer in charge of the work visits the locality at intervals of a few weeks, checks up the daily record made by the observer, verifies some of the readings and makes a measurement of the discharge to ascertain whether the relation as previously established between the quantity of flow and gage height remains unchanged. If there is a marked discrepancy then a new rating table must be made.

The record of daily observations of height of water is usually so prepared that the equivalent discharge can be entered upon it. This quantity is obtained from the rating table prepared from the occasional measurements of flow. Such record for each day in the month or year enables a study to be made of the maximum, minimum and average discharge.

Wherever practicable to do so, installation is made of other permanent measuring devices. With some of these it is usually possible to obtain more accurate results than through the occasional current meter measurements which supplement the observations of river height. Where the stream is small the entire flow can be put through a carefully constructed module or over a weir such as is shown in Pl. V. B, installed on one of the distributing canals of an irrigation system. For accuracy they should be constructed in form similar to those for which experimental data are available. Large weirs may be constructed

across streams of considerable size and automatic devices installed for recording the height of water on these weirs, thus giving continuous record of flow.

Other methods of measuring flowing water have been devised, such as the Venturi[1] meter invented by Clemens Herschel, or the Pitot tube. Colors have also been employed and observations made by the eye as to the length of time required for a few drops of coloring fluid to reach a given point. (See *Engineering News*, September 23, 1915, p. 617.) Chemical methods have been successfully tried using salt, a suitable amount of which is injected into the water, tests being made from time to time of the effluent. The speed of flow is thus found by direct observations. Indirect methods are also employed as, for example, by comparing the strength of a salt solution flowing into the stream at a certain rate with the degree of salinity of the stream as shown by samples taken at a lower point.

The velocity with which the stream flows is also computed in less obvious fashion by using somewhat empirical formulæ based on measurements of the slope or fall of the surface of the flowing water. The simplest of these formulæ is that of Chezy, published in 1775. In this the velocity is stated as the product of a constant, C, multiplied into the square root of the product of the figures representing the slope times the figures expressing the shape of the channel or $V=C\sqrt{RS}$.

The Chezy formula was developed by Kutter and others into a somewhat complicated form in which the factor of roughness of the bed of the stream has been expressed by the letter n. Various values have been found for n and these, when inserted in the formulæ have enabled a close approximation at the velocity and consequently the discharge of the stream. For example, in a smooth, cement-lined canal such as is shown in Pl. XII. A, the value of n is as low as 0.01, while for a clean earth canal it may be 0.02 and so on up, depending upon the fact as to whether the natural channel is cut in sand, gravel, or bowlders.

There is need of continued research and exercise of ingenuity in perfecting these methods for quick and fairly accurate methods of ascertaining the flow of water under the various condi-

[1] Merriman, Mansfield, "Treatise on Hydraulics," 1912, p. 89.

tions which are encountered in the investigation of the water resources of the country. Many plans for future use of the water are dependent upon the obtaining of such data; in turn these rest upon the ability of the engineer to achieve the desired results economically.

Fluctuating Flow. In projects for larger use or development of water resources, especially by storage in reservoirs, it is of great importance to study in advance as completely as possible the time and quantity of the fluctuation of flow of natural streams upon which dependence is placed. It is found, as a rule, that these changes are of many kinds; for example, there is a diurnal wave, in streams coming from the high mountains, when the warm sunlight of the day melts the snow and causes an increase in discharge with corresponding check during the cool night. The effect of the heat of one day may give rise to a maximum flow, possibly at midnight or early morning of the next day, at some point lower down the stream. There is also the variation in quantity from day to day, resulting from the constant changes in temperature, wind movement, and precipitation.[1]

More important is the seasonal change; the streams usually have a flood stage in the spring and decrease to a minimum in August or September. Each year also shows a marked difference from that of the preceding, so that in any study of the behavior of streams it is necessary to have observations continued through a long period of time. It is probable that in the course of forty or fifty years most of the peculiarities of any given stream will be developed, unless radical changes are made on the watershed by cutting the trees or by cultivation.

There is a notable difference in the behavior of rivers in different parts of the country. Those of the humid east, with rainfall fairly uniformly distributed throughout the year, are not subject to fluctuations relatively as great as those in the arid west, where the spring flood may be succeeded by complete drought. (See page 94.)

Range of Fluctuation. Computations of run-off when

[1] See "River Discharge," by Hoyt and Grover, 4th edition, Figs. 37 and 38.

stated in tabular form by days, months, and years, permit comparison to be made and conclusions to be drawn concerning streams in different parts of the country. The streams issuing from the high summits of the western mountains are quite similar in character to the rivers of the humid region because of the fact that these mountains, rising to great height, receive a relatively large precipitation, and the hill slopes, covered often with forests, are more humid than the surrounding country. In their lower reaches, however, the western rivers take on a different character and the waters coming from the hills may disappear into the broad sandy beds during the extreme heat of summer. Thus the fluctuations of these streams at lower points may be from zero almost to infinity, in that an extraordinary cloudburst may send down such quantities of water as to completely overflow the banks and drown the adjacent country.

In the case of rivers of a humid region there is a more steady flow. Their beds rarely, if ever, become completely dry, but their flow continues until it finally reaches the ocean. Thus the minimum is considerably above zero and the maximum, on the other hand, is rarely as high as in the case of the erratic streams of the West. Because of this small range of flow, the waters as a whole are clearer as there is less violent attack on the beds and banks, such as characterizes the sudden floods of the arid region. The water of eastern streams, as a rule, is considerably softer than that of the western and is more nearly free from the so-called alkali which plays such a large part in problems of conservation in dryer areas.

Because of the fact that the natural or unregulated streams fluctuate thus widely, it is desirable to ascertain the range of these fluctuations for various periods of time, such as the day, month or year. The regular diurnal changes as described on page 110 are usually small, but regular. The monthly range may be quite considerable. It is usual to state the maximum and minimum quantities which occur on any one day or shorter period of time in each month, and also to average the figures for the entire month, giving the rate of flow in terms of cubic feet per second.

It is also desirable to compare the quantity of water deliv-

ered during a month with the area of country from which the water is derived, or in other words, to divide the average run-off for the month by the number of square miles drained. This gives a method of comparing one drainage area with another. From a mountainous area the run-off per square mile may be from 5 to 20 cubic feet per second per square mile. Going downstream, however, and including larger and larger catchment areas or more nearly flat land on which the rainfall is less, the proportion rapidly decreases until near the mouth of the river the run-off per square mile drained may be a tenth of the rate found above. (See also page 94.)

Depth of Run-Off. For certain purposes it is also convenient to compare the run-off during various years from certain drainage areas in terms of depth over the area. For example, from the tributary to a given reservoir, the amount of water which flows into the reservoir may be stated in depth in inches and thus be compared directly with the depth of rainfall. The rain gages may show during a given month that 3 inches of rain fell. The run-off received in the reservoir or the amount which flowed in the stream, if all caught and put back in the catchment basin, would perhaps cover an equivalent flat area to the depth of one inch; thus a third of the rainfall was available for storage.

These several quantities, the maximum, minimum, and mean daily discharge in cubic feet per second; the quantity per square mile drained and the depth of run-off in inches are usually computed for each month of the year for all of the points of measurement on any given stream—thus enabling direct comparison and a study of the quantities which exist.

Ordinary and Average Flow. The item of most importance in considering many of the problems of water power or of conservation by storage is as to the average or ordinary flow of a stream which may be depended upon. It is, of course, necessary also to know the maximum as noted above and to make suitable allowance for the extraordinary floods; also to ascertain whether at certain seasons the stream will probably drop to a minimum or become dry; but throughout all the computations, the ordinary condition is of prime interest. In this connection,

it is important to point out the difference which exists between the average flow and the ordinary flow. In streams having relatively small fluctuation, the average and the ordinary flows are practically the same, but in streams of erratic behavior, with floods which may occur in rapid succession during a single month and not again for years, the average flow is considerably higher than the ordinary and a statement of the average may be misleading.

The ordinary or natural flow are terms in common use and like many such expressions must be carefully explained in order to prevent misunderstanding. Various definitions have been attempted of which that given by Robert E. Horton in *Engineering Record*, May 2, 1914, p. 495, is probably the most useful. He gives it as the most uniform or median stage and arrives at it by taking the flow for each day in the year, arranging these quantities in their order of magnitude. Then it is evident that the middle or median quantity in the table will represent the ordinary stage or discharge, as the case may be. That this is the most usual stage or discharge is evident, since the stream is just as likely to be higher as lower. As to ordinary high water, and ordinary low water, the finding of satisfactory definitions may appear a little more difficult. Mr. Horton has, however, used the following definitions for the terms:

"The ordinary stage is the median stage."

"Ordinary high water is the median point for stages or discharges of the stream which are above the median stage or discharge for the whole record."

"Ordinary low water is the median point for stages or discharges of the stream which are below the median stage for the whole record."

"As a rule, the ordinary stage of a stream is less than the average or mean stage: as a rule a stream is below its mean stage more than one-half of the time and above its mean stage less than one-half of the time."

There has been as yet no general agreement among engineers with reference to the definition of ordinary flow, and the term "natural" flow has been used synonymously. It has been given

interpretation by the courts at various times, as noted in the "Cyclopædia of Law," to the effect that "the natural flow is the quantity of water ordinarily flowing in the stream at the times when its volume is not increased by unusual freshets or rains."

Natural and ordinary flow are in some cases, at least, used synonymously. Thus in 67 Neb. 325, "Hall at most, as a riparian owner, was entitled to only the ordinary and natural flow of the stream."

Another method of ascertaining the ordinary flow is to arrange the table of daily discharges, listing them in the order of magnitude, then divide this table into four parts, taking the average or middle half of the values listed. A third method consists of simply finding the average of the quantities in the middle third.

In order to illustrate the difference in the results obtained by these various methods, the following figures have been prepared for two of the important streams on the Canadian boundary in northern Montana. One of these, the St. Mary River, rises in the Glacial National Park of Montana and has a relatively steady flow. There are, however, occasional floods which tend to increase the average. The other stream, the Milk River, rises in more open country and does not have the steady flow characteristic of streams but depends for its supply largely upon occasional storms. Thus the flow is more irregular and the influence of the erratic floods is shown in raising the average.

The ordinary flows tabulated below have been computed under the direction of N. C. Grover, by three slightly different methods, described above, as follows:

First, by what may be known as Horton's method (R. E. Horton, *Engineering Record*, May 2, 1914, p. 495), the result is the median value as described above.

Second, which may be known as the middle half method, the result is the average of the values in the middle half of the values listed; an adaptation from rules in Rankine's "Manual of Civil Engineering."

Third, consists of simply finding the average of the quantities in the middle third.

In each method it is necessary to list the values for a year in

their order of magnitude, or else determine their frequency between limits selected arbitrarily. The results follow:

1. St. Mary River near Cardston, Canada, 1910.
   1. Ordinary flow by Horton's method 700 sec.-ft.
   2. Ordinary flow by middle half method 729 sec.-ft.
   3. Ordinary flow by middle third method 723 sec.-ft.
   4. Mean annual flow as published 917 sec.-ft.
2. Milk River at Milk River, Canada, 1913.
   1. Ordinary flow by Horton's method 69 sec.-ft.
   2. Ordinary flow by middle half method 68 sec.-ft.
   3. Ordinary flow by middle third method 65 sec.-ft.
   4. Mean annual flow as published 155 sec.-ft.
3. Milk River at Havre, Montana, 1910.
   1. Ordinary flow by Horton's method 38 sec.-ft.
   2. Ordinary flow by middle half method 46 sec.-ft.
   3. Ordinary flow by middle third method 37 sec.-ft.
   4. Mean annual flow as published 143 sec.-ft.

The ordinary monthly flow for St. Mary River at International Boundary and Kimball has also been computed. The records used were for 1904 to 1908 and 1910 to 1914. The month of January, 1904, was estimated at 200 second-feet, thus making available ten complete years.

1. Ordinary flow by Horton's method 540 sec.-ft.
2. Ordinary flow by middle half method 622 sec.-ft.
3. Ordinary flow by middle third method 595 sec.-ft.
4. Mean annual flow for ten years 939 sec.-ft.

If reservoirs on a stream are so situated that they can receive the entire flow irrespective of time, then there is less importance attached to this difference between the average and ordinary flow, but if the floods must be conducted through canals or artificial structures, it can readily be appreciated that it is the ordinary flow which has value and for utilizing which plans may be developed. The erratic floods which tend to raise the average are often of more injury than value and in any comparison of streams the inclusion of these in the averages may lead to fallacious conclusions.

To illustrate, if we have two streams of approximately the same average flow we may find on analysis that on one of them practically all of the water occurs during one or two storms and for the greater part of the year the bed is dry. Under these conditions it may be practically impossible to utilize any considerable proportion of this average. On the other hand, the stream of about the same flow may have such regularity of behavior that the entire volume can be successfully handled. The difference between these streams will be brought out if, instead of depending upon the average, we have before us the ordinary flow, namely, that which is most usual and which in the case of the flashy stream may be very nearly zero, because the bed is dry for a great part of the year.

CHAPTER VII

STORAGE OF WATER

NECESSITY. The ability to obtain enough water at the right time and place makes possible an increase of food supply, of population, and the development of many industries. Without water secured by storage it is impracticable for many communities to increase and prosper or for men to find steady employment in various industries. If there is not sufficient water during summer droughts, agricultural areas are abandoned and many mills are compelled to shut down, discharging the workmen temporarily. Important electric light plants operated by steam have been crippled at critical periods through lack of condensing water for their engines. As cities and industries grow there becomes a greater dependence upon an artificially regulated water supply. The investment of large sums of money in providing works for insuring a uniform or full amount of water at the proper time is one of the marks of advancing civilization.

The primitive savages, appreciating the needs of water storage, enlarged or improved the water holes, or made cisterns. Among the oldest monuments of engineering skill are the works connected with water supply. Through all historic time there has been some progress, but the last two decades have been particularly notable for the great increase in number and size of storage works and in the larger application of engineering skill and appliances in building these.

The storage of water is necessary for two contrasting conditions; first and primarily, to provide water when needed, and second, to hold back an excess which might be destructive. This latter use of storage on a large scale is comparatively recent, although from early times dykes and low dams were built to restrain flood water and in some cases large reservoirs were

constructed to regulate floods. The systematic development of these restraining works for river regulation or control is now recognized as a matter vital to the future growth of the country.

In Egypt large depressions in the desert near the valley of the Nile were utilized many thousands of years ago, the flood waters when in excess being conducted to low-lying reservoirs in order to prevent extremely high water from injuring the irrigated lands. In some cases it is probable that, as stated by Sir William Willcocks, portions of this excess water thus stored were returned to the river in time of low water. The modern British engineers in Egypt have studied the methods of these ancient and forgotten engineers and although conditions have changed somewhat, especially through cultivation of the bottoms of some of the old reservoir areas,—making it impracticable to restore all of these older works,—yet similar enterprises have been undertaken in holding back a certain portion of the flood in basins built in the main course or valley of the river itself. The lakes and swamps near the headwaters of the Nile are being explored with a view to regulating the outlets of the natural basins which exist there and to converting these basins into storage reservoirs.

In the western part of the United States, particularly along the great Colorado River of the West, there are similar conditions where reservoirs may be built not only on the headwater streams but also at points lower down.[1] To the west of the Colorado River in southern California is a deep depression extending about 300 feet below sea level, similar to the sunken valleys in the desert west of the Nile. The lands around this depression, lying both above and below sea level, known as the Imperial Valley, have been overflowed in past ages. At the present time they are being irrigated in part by the water of the Colorado River. The future development of this area to its full capacity is dependent upon water storage, not only to furnish a needed supply in years of scarcity, but for increased protection against floods such as have produced disastrous results in recent years.

[1] "Colorado River and its Utilization," by E. C. LaRue, U. S. G. S., Water Supply Paper No. 395, 1916.

The effect of these floods in breaking over the river banks on the way to the Salton Sea, which occupies the bottom of the Imperial Valley, is shown in Pl. XVIII. B. This illustrates the condition of the farm lands which have been cut away in part by the uncontrolled waters. The deep, rich soil has been rapidly eroded into gorges of fifty feet or more in depth, thousands of acres being ruined. These flood waters are now usually controlled by dykes, but the ultimate solution of many difficulties and the realization of the largest opportunities will come from the consummation of well-considered plans of storage.

Modern Methods. Recent progress along lines of water conservation by storage has resulted largely from the adoption of modern machinery and from the application of more highly developed principles of efficiency and economy in handling materials. There are relatively few new principles involved, but the resulting structures are quite different in plan and appearance from those of olden times. The experience acquired in large numbers of works recently built has added greatly to the knowledge of the subject. The relatively few accidents or failures which have taken place—although disastrous—have served to shed light on many conditions which in previous years were not fully appreciated.

The principal advances have been in the adoption of quicker and more economical methods of placing earth in dams and in protecting it from erosion; also in methods of placing concrete and in the proportioning of the dimensions of dams, particularly those having an arched form or consisting of slabs or decks supported by buttresses. Here a wide diversity of practice is seen, accompanied by a rapid advance in economy of construction. The demands made upon the hydraulic engineer have forced him to put into play all his ingenuity and to use to the utmost all his wits to meet the rapidly expanding range of uses of water. He is being called upon to solve more and more intricate problems growing out of the increasing density of population and the multiplication of industries.

In the practice of his profession, especially in relation to the larger problems of storage, the engineer must have available the results of meteorological observation of the occurrence of water

in the form of rain or snow, and must obtain data, as noted on page 54, as to the variations in precipitation which take place from day to day and from year to year, as well as to the resulting stream flow. He must consider the topography of the country and the possibility of building storage reservoirs to conserve the supply; he must be prepared to discuss the questions of river control, of erosion and sedimentation and of the use of water in domestic and municipal supplies, also in the production of power in manufacturing and for other purposes or necessities created by the ever growing needs of a civilized community.

In earlier years when the sparse population was occupied mainly in agricultural pursuits and the industries were few, there was usually enough water and to spare, especially in the humid areas of Europe and America; no great difficulty was found in procuring ample drinking water and there was little interference of one community with another through pollution by discharging sewage or manufacturing wastes into the streams. With the rapid change from a rural to an urban population and with the growth of manufacturing centers, the question of obtaining adequate supplies has become more pressing; joined with this have been conflicts between the diverse interests of manufacturing, power production and navigation. All of these changes call for more research, more detailed study of the data available and a larger application of the results in preparing engineering plans.

Topography. The conditions which render storage feasible on a large scale are quite rare. There must necessarily be a combination of a broad basin or nearly flat valley, with a narrow outlet, so situated that an adequate supply of water can be brought to the basin. The proximity of suitable material with which to form a dam must be such that its cost in the dam as well as that of acquiring the necessary land and water must be within reasonable limits. This is quite unusual; out of a hundred localities where it is popularly supposed that water might be stored there are only a few which comply with all the requirements of economy.

In most cases the outlet to any broad, shallow valley is itself broad and the length of structure required to close this outlet

may be too great to enable a dam to be built within the required cost. If the outlet to the valley is narrow it usually happens, from well-understood geological reasons, that the valley floor is so steep that a dam of prohibitive height will be required to hold back any considerable amount of water. If these conditions are favorable it usually happens that the location does not have a watershed large enough to furnish an adequate supply of water or the site is too high above the surrounding country to enable water to be brought to the basin. Again, if this rare combination of capacity of reservoir, short and low dam, and adequate supply of water exists, then comes the question of material for the dam and the cost of putting this in place, keeping this cost so low that the finished structure falls within the requirements of funds available.

Mountain Storage. The conditions which have given rise to the mountains with their highland valleys are most favorable for the creation of reservoir sites; hence the most striking examples of storage works are to be found in a mountainous country. There is also usually ample good building material at hand and in some cases nature has already formed small lakes, particularly at the headwaters of the streams where glacial action has resulted in innumerable ponds. The outlets of some of these may be closed at relatively small expense and the level of the water surface raised, giving increased storage capacity. There are also many valleys which in former ages contained lakes; here the old, worn-down barriers can be restored at relatively small expense. The chief difficulty encountered in connection with these mountain reservoirs is that of securing an ample supply of water, because of the fact that the mountain valleys lie at high altitudes, often hundreds of feet above the level of the main streams.

The typical mountain reservoir site offers advantages in that rock suitable for masonry is usually found in the vicinity and the foundations for the dams are firmer than in the case of sites in the more open country. The loss by evaporation from the surface of the reservoir built in the mountains is usually small because of the prevailing low temperature. One of the largest and most economical of the mountain reservoir sites is Lake

Tahoe, shown in Pl. I. A. Another notable locality is Jackson Lake in Wyoming, shown in Pl. IV. B. This is south of Yellowstone National Park and is at the head of Snake River. By building a dam 5,000 feet in length at the outlet, the United States Reclamation Service has made available a storage capacity of 789,000 acre-feet at a cost of about a million dollars.

Plains Storage. The rivers issuing from the mountains increase in volume as they descend, thus affording an ample supply of water for storage in the lower courses. This condition is in striking contrast with the scanty amount available at the headwater basins. Because of this, it is often necessary to consider the question of water storage at points out on or adjacent to the lower valleys or plains through which the rivers flow. The disadvantages, however, in these lower altitudes are usually great, because of the scarcity of good reservoir sites and of suitable material for building the impounding dams. The methods to be employed and plans to be adopted are less obvious in connection with these lower reservoirs. When built, the loss by evaporation and seepage must be taken into account to a larger degree than in the case of the storage works at higher altitudes.

Among the notable instances of plains reservoirs is the Deer Flat of the Boise Project, Idaho, built to hold the flood waters which occur below the upper mountain reservoirs. The flat itself was not particularly well adapted by nature for an artificial lake, as it required several earth dams of considerable length to inclose the basin. One of these dams is shown in Pl. V. D. This dam is of earth, 7,200 feet long and 40 feet high, containing 1,207,670 cubic yards.

Another plains site is that of the Cold Springs Reservoir of the Umatilla Project in Oregon. The view, Pl. V. C, does not give the impression of a favorable locality. It is simply a depression in a broad sagebrush-covered plain, and with a wide outlet. Yet this was the best place which could be found for the storage of the erratic floods of the Umatilla River. The seepage losses are large and the basin is shallow—but in spite of these disadvantages, the reservoir is performing its part in the development of the country.

Surveys. The first step to be taken in considering the prob-

lem of water storage is that of a general reconnoissance of the whole country under consideration, including both mountains and valleys. If a good topographical map, such as that prepared by the United States Geological Survey, is available, a great part of the time and expense of the reconnoissance may be saved. In any event, whether there is a map or not, the reconnoissance should be made by the best man available—one experienced not only in the larger details of construction but accustomed to form correct judgments as to topographic features and hydrographic conditions. It is largely upon the exercise of such judgment that the extent and character of future detailed surveys depend and the economical working out of any plan which may be adopted. It not infrequently happens, where the preliminary work was done by men inexperienced in the matter, that the wrong beginning has been made and unnecessary expenditures have been incurred, because in the preliminary study certain important features were not appreciated.

When the general conditions, both of topography and hydrography, of the river basin have been examined, it becomes necessary to prepare some definite estimates of the relative capacity and cost of various storage sites. Although it may be possible to judge by the eye something as to the relative value of various basins, yet in the mountains particularly, there are many optical illusions as regards slope. Carefully run lines of levels and topographical sketches are necessary to verify the first assumptions. It may be necessary to follow these first topographical maps with others even more detailed as the choice begins to narrow down to a few alternatives. The basin ultimately chosen should be mapped with a contour interval of at least 10 feet vertically and in some cases of a smaller scale of 5 feet. It is important to know the capacity of the reservoir for each foot of water height and the corresponding area exposed to evaporation.

At the dam site where the heavy expenditure is to be made, there is need of even more careful topographic surveys. It usually happens that when the best basin has been chosen for a reservoir there is considerable latitude for judgment as to the

location of the dam itself. A change of a few feet up- or downstream may involve notable increase or decrease in the quantity of material to be handled. The various possible locations should be surveyed with such degree of care as to show contours at two-foot vertical intervals. On this map should be placed all facts connected with depth to bedrock or to impervious strata. Ample time should be allowed for making these topographic maps and related studies. Every dollar economically spent on this work may result in a saving of $10 in construction. As a rule, too little time has been allowed for work of this kind, as it usually happens that when the people building the work have reached the point of making detailed surveys they are anxious to begin to assemble the construction plant. The engineer is thus often swept off his feet by the demand that work be begun and is not given the opportunity of thoroughly exploring the foundation and of considering the most economical method of handling the material available.

The surveys and examinations of any proposed storage system and of the catchment area tributary to it will usually reveal the existence of several basins or depressions which may be converted into reservoirs. They should also show the character of material available for construction and the foundations upon which each proposed structure must be built. Having obtained these essential data, the next question for the consideration of the engineer and of the investor is as to the relative cost and permanence of the structures which may be needed to create the necessary water storage.

Alternative Sites. It is usually necessary to examine a number of alternative locations for the site of the dam. Sometimes there must be provided not only the principal dam at the main outlet of the valley or depression, but also a number of supplemental dams or dykes to raise the rim of the basin at various points. Even if there is only one gorge or narrow outlet where apparently the dam can be located, yet there are usually points, a short distance apart, where the underground conditions may be better than at others, although on the surface all look alike. This fact can be determined only by careful exploration, usually by digging test pits or by putting down

drill holes. When the foundations are finally opened, conditions may be discovered which will force a relocation higher up or lower down in the gorge.

If the foundations are found to consist of solid rock and there is ample similar good material in the vicinity, the structure may be designed to be built of ashlar or rubble masonry throughout. Usually, however, it is desirable to consider the practicability of building the works of concrete. With the recent developments in methods in the manufacture and use of cement, it frequently occurs that economy in construction can be secured by crushing the rock which formerly would have been used in ordinary masonry, and then making a relatively homogeneous mixture of concrete instead of attempting to quarry large blocks and lay each of these separately in a bed of mortar.

MATERIALS. The essential features of any work for river regulation or for conservation of water by storage is the dam or barrier built to hold back the flow of water. This usually consists of a bank of earth or a wall of masonry or wood placed across a watercourse. With the development of modern machinery and appliances it is now possible to build dams of an almost infinite variety of materials and shapes; the principal question being as to the relative efficiency and economy of each type. These facts are determined by the position of the structure itself and particularly the character of the materials available in the vicinity; also to a large degree by the texture of the rocks or soil which occur at the place where the dam is to be built.

As regards materials, earth or disintegrated rock may be considered as the most common. The word earth includes practically all varieties of the softer matter composing the surface of the globe as distinguished from the firm rock. There is in reality no sharp line of distinction between earth or soil and rock; from the geological standpoint rock may be considered as including all of the mineral substances, hard and soft, which form the crust of the globe. It is this fact which gives rise to more or less controversy in construction work, and to avoid misunderstanding there should always be given a careful definition as to the way of distinguishing between rock and earth. From

the scientific standpoint granite, sand, gravel and clay are rock; but for engineering purposes it may be necessary to define earth as material which may be moved by any ordinary plow as distinguished from firm rock which cannot be thus easily disturbed.

The reason for this inability to distinguish clearly between earth and rock arises from the fact that most earths are formed by the disintegration of more solid rocks. As the decay proceeds there is no sharp line of demarkation between the crumbling rock and soft soil. On the other hand, the harder rocks are to a large extent formed of sand or clay which has been consolidated in the course of ages. Thus while there may be no difficulty in deciding that a given substance is rock and that another is earth there are innumerable intermediate conditions where such classification is impracticable without some arbitrary definition agreed upon in advance, such as the plow test.

In considering the materials used in building dams, we may start with the disintegrated rock in the form of clay, sand or gravel and consider as earth dams those which are built up by the proper arrangement or mixture of these substances. If we imagine that the individual particles become grouped or consolidated into larger masses, we pass into the class of loose rock dams in which, as in the earth dams, stability is secured by each block or mass resting against and being held in place by its neighbor. The next step in evolution would consist in fitting together these loose masses and causing them to adhere to each other by suitable cementing substances, giving rise to rubble masonry or if the stones are carefully squared, to ashlar masonry. Again, if instead of fitting the stones together, we crush them to smaller size and then mix them with cementing material, we have the concrete structure. The latter substance, being semifluid, can be poured or molded into form and used under many conditions where earth or rock would be inadvisable. We may also substitute timbers for masonry, building tight walls supported by suitable frames or even by a rock backing, thus having various combinations of wood, stone, earth, or cement. Metal also is used, both in sheets and in beams, replacing the older wooden dams and enabling structures of great size to be built with a high degree of economy.

Plate VI. A.

An unusually good dam site in a narrow granite gorge with bedrock a few feet below the surface. Site of the Pathfinder Dam on North Platte River, Wyoming.

Plate VI. B.

Deceptive appearance of foundations, river apparently flowing upon bedrock, but diamond drill shows that the channel is filled with bowlders and loose rock to a depth of sixty feet or more. Site of Shoshone Dam, Wyoming.

Plate VI. C.

Site of Roosevelt Dam, Arizona. Showing highly inclined strata of side walls and narrow gorge.

Plate VI. D.

Building a dam of earth, showing core wall in center with earth banks above and below, to be widened until they join, covering the core wall; test pits on hillside in line of core wall; Strawberry Valley Dam, Utah, looking upstream.

Each and all of the above-named substances and others such as brick or terra cotta have been employed in storage works, large and small. The question to be considered in each case is that of safety as well as efficiency and economy, both in construction and in later maintenance.

Foundations. The character of the foundations largely determines the material to be used for a dam. It is obvious that on a soft base, heavy masonry cannot be readily used. The crucial point and the one where failure has usually taken place has been at the base. There the hydrostatic pressure is at its maximum and under a head of 100 feet or more, water finds its way through minute cracks or joints and exerts a pressure sufficient to disrupt the weaker rocks. The character and design of the dam are dependent largely upon the foundation, both as to its permeability and its strength in holding the structure.

As a rule the spot where the foundations are to be placed is concealed by overlying loose material. A few rare cases have been found where, in the case of some of the harder granites, stream erosion has laid the bottom bare and there is no disintegration or weakening of the surface. Such a condition was found at the Pathfinder Dam in central Wyoming, where the North Platte River, as shown in Pl. VI. A, had sawed its way through a rising block of granite and was flowing between granite walls over a granite bed covered to a depth of only a few feet with loose material which had fallen from the walls.

Borings. Investigation has shown that throughout the arid west the streams have been choked with material which is washed in or has fallen from the sides so that the present bed is usually from 50 to 100 feet above the level at which the river flowed in earlier times, as shown in Pl. VI. B. It is necessary to penetrate this loose material and to ascertain before construction exactly what are the conditions of the bottom and the side of the valley where a dam is to be placed. The primitive method of ascertaining these facts is to sink a well or shaft down to and into the bedrock. Usually, however, the inflow of water is so great that without powerful pumping machinery the digging of such a shaft is impossible. To overcome this

difficulty the usual method is to drill holes of from two to six inches or more in diameter, such as those made by the ordinary well drills, and to carefully clean out each hole as it is cut downward, saving and studying the debris which comes from the bottom of the hole to ascertain the character of the material penetrated. Great skill is required in judging correctly as to whether the hole is penetrating solid material or is in loose rocks which have fallen into a depression.

An improvement on the old-fashioned hand or churn drill is that of the rotating diamond or steel point which cuts an annular hole from which a core can be obtained. This core enables an expert to judge accurately as to the character of the material penetrated. In all cases, however, great care must be exercised to see that the drill is actually working in the solid rock and not in a great bowlder; for example, at the Shoshone Dam a granite bowlder over twenty feet in diameter was encountered; had the precaution not been observed of going forty feet or more into the rock the long solid core from the bowlder would have been considered as proof that bedrock had been reached. It so happened, however, that the drill at about the twentieth foot of penetration passed into sand and gravel and then again into granite which finally proved to be the real bedrock.

In planning the field research, drill holes must be placed at short intervals across the outlet of the valley, where the dam is to be placed, and up and down the stream far enough to determine the character and slope of the underground layers of earth or rock. The holes also should be continued up on the hillsides until a place is reached above water level where pits or shafts can be sunk exposing the abutments on each side. It frequently happens that the rocks at the dam site are stratified and that water percolates along the bedding or through the joints. This condition must be thoroughly studied, as it affects the stability of any structure which may be built at this spot. It is possible to adopt methods which will render a dam reasonably tight, but for safety and economy of construction it is far better to know and anticipate any unfavorable

conditions than to attempt to rectify them after the structure has been built.

The conditions which exist at the site of the Roosevelt Dam in Arizona are illustrated in Pl. VI. C. There the gorge consists of stratified quartzite dipping upstream at a high angle. The cliffs afford excellent opportunities for quarries. The stratification of rock dipping toward the reservoir site was considered as being of advantage in that any leakage which might occur along the seams must necessarily flow uphill and be thus reduced in volume. There are, however, a number of faults or planes of fracture which intersect the rock at this place. The location of the dam, therefore, was considered with reference to these lines of weakness.

The character of the foundations and of the rock or other substance to be used in building the dam determines to a large degree not only the ultimate cost and safety but also the immediate plan of operation and the kind of equipment to be used. Under ideal conditions where there is a firm, water-tight foundation, and solid rock to be had in the walls of the valley, the plans may be relatively simple, but if, as is often the case, the foundations are weak and imperfect and there is not within easy reach a good supply of rock, then there must be a balancing of cost between bringing from a distance of a mile or more a better quality of material or shifting the site and adopting plans such as to use a greater quantity of poorer material nearer at hand. For example, on a soft foundation it may be decided to use a great quantity of earth, thus building a dam of unusual thickness as was done in the case of the Gatun Lake in Panama rather than to risk building a masonry or concrete structure on the yielding base. There is usually a wide range of conditions to be studied and it is hardly possible to make the research too thorough or to gain too much information regarding the character of the material and of its probable behavior under different forms of handling or arrangement.

CHAPTER VIII

DAMS

EARTH DAMS. The oldest and most numerous of the structures built for the control or conservation of water by storage are of earth. Many ancient dams antedate written history; some are still in use and the remains of thousands which have been destroyed through age and neglect are to be found in all parts of the earth where man has long lived. Earth dams are still being built, of larger and larger size, and with greater skill and economy than in the past. In spite of the notable development in handling other more stable materials, they offer many advantages.

Because of the fact that earth is a result of decay or disintegration, it is essentially stable, for it cannot deteriorate nor change its character; but since it consists of small particles, it is easily eroded, its form though not its substance is easily altered by rains or floods. Earth dams if properly built and protected from erosion or other mechanical change are thus among the most permanent works of man, but if not thus protected, they may be destroyed in a few days or hours.

The chief claim for consideration of the use of earth for a proposed dam lies primarily in the fact that earth or decomposed rock occurs almost everywhere on the land surface. It is, of course, of widely differing composition and texture, varying from fine silica, sand or gravel to complex silicates such as clays and silts, or it may have an admixture of organic matter and earthy salts forming more or less soluble and fertile soils. In considering earth for use in dams, it is necessary first to define what the earth consists of, as it may have a very wide range of chemical or physical properties.

The only quality common to all earth is that it is relatively loose or friable and can be easily dug or moved by hand or

simple machinery. The earth under consideration for use at some locality may consist of loose sand. It is obvious that this alone will not be suitable for building a dam of any considerable height. On the other hand, if the material is a silt or loam, this used alone will not be suitable, but mixtures of the sand and silt with possibly the addition of some gravel may result in a combination which is not only impervious to water, but can be built to withstand a considerable pressure. The study of the earthy materials available near any given dam site, and of the possible combinations of these, demands experience and ripe judgment.

The condition of the foundations with regard to permeability and strength to sustain a weight, as noted on page 127, may be such as to lead to the conclusion that, even though rock may be available, yet safety will be promoted by building an earthen structure. The question then arises as to the quality of the various deposits of earth which may be mixed and the methods of handling these and of placing them in the dam. In olden times all this work was done by hand labor, the dirt being shoveled into baskets and carried to the point of deposit. Later came the use of carts or scrapers drawn by horses, followed by the small construction railroad in which cars loaded with dirt by a steam shovel were brought to the desired place. In turn the latter method has been superseded in part by conveyors of various types and even water itself is being used to sluice the earth into place. Every year brings out some improved mechanical device for moving earth and as a result of studies by engineers or researches into the hydraulic processes, economies are being effected resulting in a low cost which a few years ago was considered impossible.

There is usually to be considered not only the question of the selection of suitable material near the chosen dam site but also that of handling it in a systematic fashion, depositing it in place with great care and uniformity, such as to secure practically water-tight conditions. An earth dam is similar in some respects to a loose rock dam in that the upper or water face should be made as nearly impervious as possible, while the downstream or dry portions may be built of coarser material.

Although it may be practicable to permit water to overflow a masonry, concrete or loose-rock structure, such action means destruction to an earth dam, and hence every precaution must be taken to prevent water from flowing over the top.

Usually in building an earth dam it is not practicable to carry the foundation down to bedrock, as is necessary with masonry structures. In all cases, however, the ground must be stripped to an impervious layer of clay or "hardpan" and the materials composing the dam placed on these and carefully incorporated with the new surface thus exposed. The selected earth to be used in the body of the dam should be slightly wet and rolled in thin layers to secure the highest degree of compactness. Layer after layer of three or four inches to six inches in thickness is thus worked into place, care being continually exercised to secure thorough compacting, no details being slighted or omitted. The results are tested from time to time to see that the body of the dam is homogeneous and does not contain any defined layers or incipient cracks into which water may enter.

In cross section, the earth dams are in striking contrast with those built of masonry or concrete in that the slopes must necessarily be well within what is known as the angle of repose. On the upstream face, these slopes are usually one foot, vertical, to three horizontal, and on the downstream or dry side, one vertical to two and one-half horizontal.

The upstream or water side of any earth dam must be protected from wave washing by some relatively hard material such as a heavy paving of rock two or three feet in thickness, as shown in Pl. VII. C, or by concrete blocks six inches or more in thickness, held in place against disturbance by storms. (See Pl. XI. C.) In some cases a thick layer of heavy gravel has been applied, as for example, on the earthen banks of Deer Flat Reservoir in southern Idaho; the waves are allowed to carve this gravel bank into relatively stable slopes. The downstream side of the earthen dams must also be protected, usually by encouraging the growth of vegetation and by preventing the washing of rain water by providing suitable gutters or drains to keep the water from gullying the surface.

The main features of an earth dam are: first, the incorporation of the lower layers with the underlying earth of the entire foundation in such a way as to prevent water from percolating along under the dam, and, second, to secure an impervious layer as near the upper or water face as possible to hold back the water from entering the body of the dam. The strength and stability of the dam are evidently decreased if the particles of which it is composed are saturated with water. Hence the larger the proportion of the dam which is dry the greater the strength.

Core Walls. It might be assumed that the entire body of an earth dam should be impervious, but experience has shown that such conditions can rarely be produced and that it is better to make the lower side of the dam less water-tight than the upper, so that any water which does succeed in entering through the upper face may escape freely below. In this way, the lower or dry side of the dam is rendered relatively more stable.

In some cases, for convenience of construction, the plans call for a vertical wall of masonry or concrete throughout the length of an earth dam as in Pl. VI. D. Under these conditions the portion of the dam above the core wall becomes saturated with water while the lower portion, cut off from seepage by the core wall, is kept nearly if not quite dry. The dam under these conditions may be considered as consisting of a water-tight wall or diaphragm supported from overturning upstream by the wet earth and held from falling downstream by the dry earth.

Where an ample supply of good clay can be found, the center core wall is frequently made of this substance, carefully puddled, or the clay is placed on the upper half or third of the dam, being carefully compacted while slightly moist. Coarser material is then placed on the downstream side to afford free drainage of the small amount of water which may penetrate the clay.

As a rule in building earth dams the use of pure clay is avoided, except for a water-tight face or core wall, and sand or gravel is largely employed, incorporated with clay, to form a mixture which is less likely to slide or slough off. Pure clay absorbs such great quantities of water and shrinks so greatly

upon drying that it is not used except under conditions where it will be kept continually wet.

PAVING. The water slope of all earth dams must be protected from wave action. As the water rises and falls in a reservoir, the shore line advances or retreats along the earth bank and at this shore line wind action produces waves which tend to cut a shelf or beach. To overcome this action and to maintain the earth slopes in symmetrical and safe conditions, it is usually necessary to pave them with rock or in some cases with cement blocks. An example of ordinary paving is shown in Pl. VII. C and in Pl. XI. C, this being on a portion of the Owl Creek Dam of the Belle Fourche Project, South Dakota. The paving is usually placed by hand on a gravel base, the stones being of such weight and so carefully placed as not to be liable to be drawn out by the waves.

HYDRAULIC DAMS. The use of water to transport earth for the building of dams is being steadily extended because of the economies which are possible under favorable conditions. The practice is the outgrowth of hydraulic operations carried on by the gold miners of California. The debris which they moved, as stated on page 134, was of such great volume that it obstructed the streams and suggested to ingenious men the practicability of utilizing the method for filling depressions or building banks. The illustration, Pl. VII. A, gives an idea of the way in which the material is moved. In the foreground is a hydraulic giant or nozzle from which water is issuing with great velocity. This water is obtained from some high mountain stream, being conducted by gravity through wooden flumes or it may be pumped from lower ground. The main object to be achieved is to have an adequate pressure such as to make a stream which will tear out the loose soil and small rocks. As these roll down they are caught with the muddy waters and carried away on flumes built at a grade sufficient to enable the water to transport stones weighing sometimes as much or more than 100 pounds.

The flume for transporting the debris is constructed in such a way as to divide and spread the material over the surface of the dam to be built. By manipulation of the flumes, it is pos-

Plate VII. A.

Earth dam built by hydraulic process, washing the earth and loose rock from the hillside and sluicing the debris out to the site of the dam. Conconully Reservoir.

Plate VII. B.

Earth dam built by hydraulic process; spillway at left in recent rock excavation. Conconully Dam, Okanogan Project, Washington.

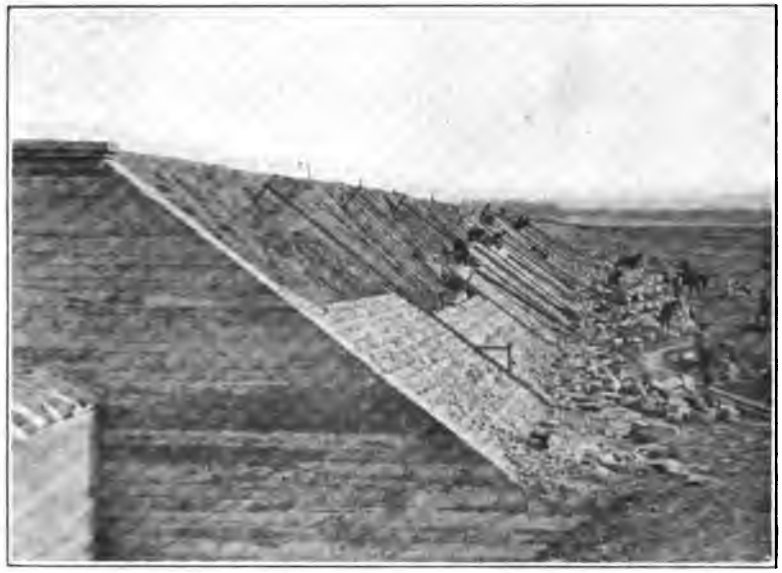


Plate VII. C.
Paving on water side of earth dam, Belle Fourche Project, South Dakota.

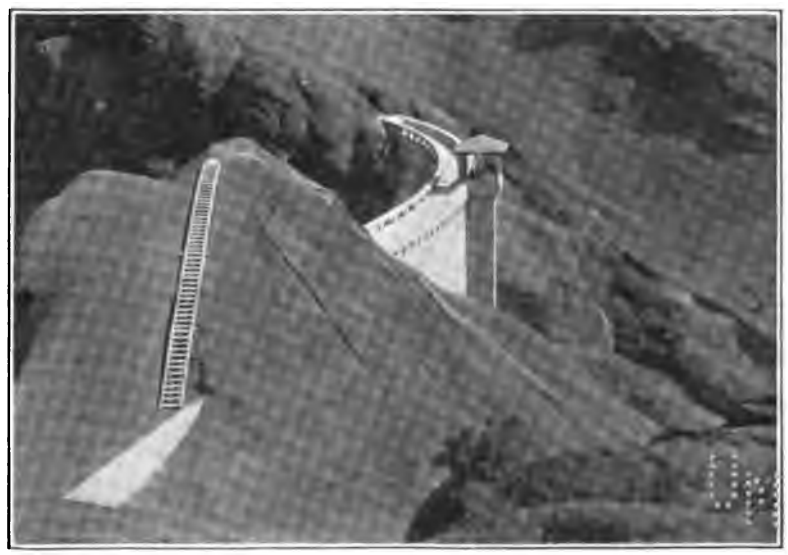


Plate VII. D.
Concrete storage dam, at East Park, Orland Project, California.

sible to drop the larger rocks on the outside of the proposed dam and to leave the smaller sand and gravel nearer the center, the finest silt being placed at the center or near the upstream side. As a result there is formed a dam such as that shown in Pl. VII. B, the outside being covered with heavy stone to prevent erosion and the inside consisting of fine water-tight materials.

Among the examples of the dams built by this method are the Gatun Dam at Panama, Necaxa Dam in Mexico, and also the Calaveras Dam in California now under construction. A smaller dam built by the Reclamation Service for the Okanogan Project, Washington, Pl. VII. B, has been mentioned. The Necaxa Dam in Mexico and also the Calaveras Dam in California are notable because of the fact that in building each of these failure took place under almost identical conditions. Clay filling, deposited in water and forming the interior of the dam, did not dry as it increased in height, but continued of semiliquid consistency until the pressure laterally pushed out the upstream side and the clay flowed into the unfinished reservoir. In the case of the Necaxa[1] Dam the failure occurred on May 20, 1909, when two million cubic yards of earth and rock had been placed; at that time about 720,000 cubic yards flowed into the dry reservoir. In the case of the Calaveras,[2] the failure occurred on May 24, 1918, when 2,800,000 yards had been placed; of this, 800,000 yards flowed inwards. These failures illustrate on a large scale the instability of the undrained clay and the necessity of observing suitable precautions in permitting it to dry out slowly. The hydraulic process requires great skill, but for handling sand, gravel, small rock or mixtures of these with clay and silt this method has been found to be generally economical.

A loose rock dam such as that described on page 169 at Minidoka on Snake River in Idaho, may be considered as closely related to the hydraulic dam, since a large part of the material has been sluiced into place. It forms an intermediate stage between the solidly constructed and carefully laid masonry dam and the ordinary earth dam. It possesses certain advantages

[1] *Engineering News*, July 15, 1909, Vol. 62, p. 72.
[2] *Engineering News-Record*, April 11, 1918, Vol. 80, p. 704.

in overcoming local difficulties and permits the utilization of materials and of forces which at first appear to be unfavorable. It is under conditions of this kind that the engineer shows his highest ability in turning to advantage the conditions which appear to oppose his efforts but which on research can be made to serve the larger needs of humanity.

Timber Dams. Mention should be made of timber dams which, although no longer built in as large numbers as in former decades, are still in use and are occasionally employed, especially for temporary structures such as coffer dams. In the heavily forested areas among the mountains where timber is plentiful, it is still being used in dams erected in connection with lumber operations. Many of the works of river regulation and of water conservation have been made practicable by using timber and at a later day, when success has been assured, more permanent materials have been substituted.

The timber dams are of many varieties and shapes. In most of them the framework has been constructed with an inclined deck of plank or a series of decks, the upper face being sloped upstream and held down in part by the weight of the water resting upon it. Lower decks or aprons are provided to conduct the water away from the base of the dam and prevent undercutting. In many instances rectangular log cribs have been built and filled with heavy stone, making a combination of timber and stone structure, the weight of the stone holding the timber in place and the timber protecting the stones from being carried away by the force of the flowing water.

Loose Rock Dams. The ideal structure for water storage is a massive dam firmly set in rocky walls—but like many ideals, it is not always practicable of achievement. This is usually because of lack of suitable foundations such as are sufficiently strong to carry the weight of the wall or because of the difficulty of obtaining in the vicinity a sufficient supply of rock of proper shape and quantity to build a dam. Wherever conditions are favorable, masonry is being employed and probably will be used indefinitely, although concrete is rapidly rising in favor.

There is a wide range of rock dams, from the simplest primitive type of a pile of loose rocks supporting a relatively imper-

vious layer of earth to the ashlar masonry, each unit of which is carefully dressed and laid in mortar or with cement joints. Loose rock dams are occasionally built but under somewhat exceptional conditions. For example, the Minidoka Dam in southern Idaho, noted on page 169, illustrates how certain difficulties have been overcome. The river where the dam was built was of too great a size and volume to be diverted through a tunnel or flume. Thus it was necessary to build a dam while the river was flowing over the foundations. To do this large rocks were dumped at the site, the size of the rocks being sufficiently great so that the force of the current did not wash them away. By placing these rapidly, it was possible to retard the flow and cause the water level to rise. At the same time the stream penetrating the loose rocks and escaping in large volume below tended to consolidate the masses by washing the loose pieces into place.

A loose rock dam of this character, built of stones as large as can be handled, is in effect a barrier which withstands the pressure or attack of the water by its own mass or weight. The body of a dam thus composed of big and little pieces of rock is, of course, permeable to water. Its function is to hold in place the water-tight diaphragm or apron placed on the upstream side. To put it in another way, a loose rock dam consists of a relatively thin water-tight wall or layer of steel, wood or clay held in place by a heavy mass of pervious material. In constructing such a dam, the larger blocks are thrown or dropped into the stream or depression to be closed. On the upstream face smaller and smaller stones, gravel, and sand are applied in succession, gradually reducing the size of the interstices and finally on the upper water face is put a layer of clay of such fineness that the water cannot penetrate it.

In some cases where the dam can be built in the dry, the impervious layer consists of a plank or steel or iron covering suitably held in place. Such loose rock dams, if carefully built and maintained, may serve indefinitely and at a cost—when interest on this investment is considered—far less than that of the more substantial masonry structure. There is, however,

always the element of doubt as to what may happen, especially in those portions which cannot be inspected.

Masonry Dams. In contrast with the loose rock dams are masonry structures in which the rocks instead of being dumped into place are carefully quarried, dressed to a certain size and then laid in mortar or with cemented joints so nearly water-tight that no perceptible percolation occurs. Such masonry dams have been built to a large extent in the past, but because of the expense, the majority of the newer structures are being built of concrete. There are certain exceptional conditions, however, where masonry works may be considered. These have an advantage in popular opinion at least, because of their massive appearance and the fact that well-laid masonry has endured through many centuries.

Until within the last generation the typical dam was one which depended for its stability upon the weight of the material used. It was assumed that tension in masonry should not be permitted and that at any horizontal plane through the dam the weight of the material resting upon this plane, when considered in connection with the pressure against, would be so adjusted that the resultant force would fall within the middle third of the plane. The theoretical section thus became a rectangular triangle with vertical water faces and downstream slope approximately two feet horizontal to three feet vertical. Additional width was given to the top of the apex of the triangle in order to provide for a roadway, and in some cases near the base a slight curve was introduced as in the profile of the Croton and other dams of the New York water supply and in the Roosevelt, Elephant Butte, and similar masonry dams of the United States Reclamation Service.

Concrete Dams. The use of concrete for dams has rapidly increased because of economy in handling the material due to modern methods and machinery, and because of the fact that the concrete may be poured or molded into forms most advantageous for the particular use. In comparing a concrete with a masonry dam, we may consider that the aggregates instead of consisting of great stones carefully laid are replaced by little pieces which, because of their small size, can be easily handled,

mixed with mortar and conveyed by rapidly moving machinery. While it is comparatively difficult to obtain large blocks of stone suitable for masonry, it is easy to get rock fragments or to crush the imperfect large blocks containing soft spots or cracks into small pieces, each of considerable unit strength. In the case of a single large block, the machinery for handling it must be ponderous and slow moving; the operation of bedding each rock requires great care and a considerable expenditure of time.

The shaping of the dam to conform to natural conditions or to give the greatest strength with the least amount of material is practicable with concrete to a far greater extent than with large masonry blocks. (See Pl. VII. D.) It is possible to arrange machinery so that it can crush and size the rock, mix it with other aggregates and have a continuous process. It is even possible to inclose the work and continue construction during extreme weather when it would not be practicable to operate heavier machinery.

The question has been raised for investigation as to whether it is preferable to attempt to place in the concrete large dimension stones or pieces weighing several tons, or on the other hand, to reduce all of the stone to small pieces fairly uniform in size and to handle these systematically by modern high-power and high-speed machinery. The present tendency is toward a systematic organization of machinery and men such that one simple procedure is followed day and night, continuously for months from the time the structure is started until it is finished. It has been found that, although theoretically at least there might be an advantage in using large stones, bedding these in the body of the dam, yet, as a matter of fact, the time spent in quarrying and conveying these, and particularly in setting or bedding them in place, interferes with the otherwise orderly procedure so that the gain from their use is not as great a source of economy as was anticipated, nor is it apparent that the strength of the structure is increased.

In most instances the materials in the quarry available for building the dam are of such character that the obtaining of large blocks is a matter of considerable expense, necessitating

much stripping and waste of material. If the attempt to secure such large blocks is abandoned and the firm material from the quarry, irrespective of size, is broken up, run through a suitable crusher and selection made automatically by screens and otherwise of suitable small pieces, the proportion of available material is greatly increased; there is less waste in the quarry and in the subsequent handling, and more than this, the machinery can be operated at a relatively steady rate. Thus with the development of machinery and effective methods of organizing equipment not only is the use of ashlar or rubble masonry declining rapidly even for massive structures, but also the use of large blocks or "plums" in concrete is decreasing in favor of the more uniform mixtures.

As yet no limit has been set to the size and height of structures which may be built of masonry, and particularly of concrete. The highest dam in the world, so far as known, is that built by the Reclamation Service on Boise River in southern Idaho, known as the Arrowrock Dam, Pl. VIII. A, 350 feet in height and 1,100 feet long on top. This is a curved structure, of gravity section, containing 585,000 cubic yards of rubble concrete, built with expansion joints and with inspection galleries, Pl. VIII. B, running through it in such a way as to permit continuous observation of the behavior of the dam, including the temperature changes and percolation which may take place.

There is nothing as yet developed which would indicate that the limit in height has been reached, or that it is not practicable, by increasing the dimensions, to build structures of even greater size. Theoretically there may be a point where the hydrostatic pressure on the foundations will severely test the porosity of some of the materials employed, but it is proper to assume that such limitations have not yet been reached, and that by proportioning the structures so that the pressure on the base will not be excessive, provisions may be made for still higher dams. In all cases care must be exercised in securing proper drainage of the foundations and of the dam itself, so that any water which may penetrate the foundations or get into

the body of the dam may escape freely without accumulation of upward pressure which may tend to lift the structure.

For relatively long and high dams the straight gravity section appears to be the best type; but in narrow canyons it is possible to secure higher economy of material combined with safety by constructing what are known as arched structures. These may consist of a single arch, Pl. VII. D, in which the radius may be the same from the top to the bottom of the structure or in which greater economy in material may be obtained by changing the length of the radius of the arch so that the same angle is subtended. For long low dams the so-called buttress type may be more economical than the gravity. Among these may be included the multiple arch type in which there is a combination of buttress and arch usually inclined to the horizontal. There is much yet to be done in the way of research and study of economical design as well as of materials of construction.

GATES. In connection with every reservoir or dam for holding water, provision must be made for regulating the outflow so that the stored water may be available when needed. The character and position of the outlet are determined largely by the foundations of the dam. As far as practicable the outlet and gates should be built independently of the dam and located in solid rock so as not to introduce points of weakness in the dam itself. The ideal condition is to place the gates on solid rock at one side of the structure. Occasionally, however, it is necessary to build these through or in the body of the dam and in such case great care must be used to prevent water from entering the material or percolating along the conduit. With earth dams the outlet should be placed on the solid undisturbed base and should be provided with cut-off walls to prevent water from following along the surface of the outlet pipe or tunnel. Many failures have resulted from lack of suitable care in this particular.

The types of gates ordinarily employed are vertically sliding valves, usually rectangular and carried on friction rollers. For smaller outlets the circular valves such as are used on city water

pipes are employed and for low heads or emergency outlets occasionally the hinged butterfly type is used.

It has been found that the larger valves or gates leading from the reservoir should be placed and operated if possible in such way as to avoid opening them when under a pressure or head of 100 feet or more. While it is possible to open or close them under these high heads, yet the erosive action of the sediment-bearing waters and the vibrations set up introduce so many complications or dangers that with deep reservoirs it is safer to provide methods of letting out water at various elevations, gradually letting it down through successively lower outlets and using the lowest outlet only when the water level has sunk below that of the higher gates. One of the latest and most striking instances of this arrangement is in the case of the very high Arrowrock Dam on the Boise River in southern Idaho. Here the gates are placed in a series at various elevations. The highest row of gates or valves is shown in Pl. VIII. A and in Pl. X. A. These are of the Ensign type, circular in form, as shown in the picture. These valves are operated from the gallery inside the dam, as shown in Pl. VIII. B, the operating cylinders for controlling these balance valves having been placed inside the dam at a point convenient for access; at the same time provision is made for inspecting the changes which may be taking place on the interior of the dam.

As a rule all of the gates for the outlets through or over a dam are placed at the upper end, so that when the gates are closed water is excluded from the pipes or conduits within the body of the dam. In the case of earthen dams, for example, with sloping water faces, this necessitates the building of an outlet tower rising from the upper toe of the dam and thus standing out in the reservoir when water rises to its greatest height. This tower is connected at its top with the roadway on the dam as shown in Pl. XI. B and Pl. XI. D.

Spillways. In making plans for any dam, whether masonry or earth, there must be ample provision for spillways for passing excess water, especially that of unusual floods. In the case of a solid masonry or concrete dam of moderate height, the entire crest may be made into a spillway, but as a rule it is wiser to

Plate VIII. A.

One of several rows of sluice gates to control water flowing through the Arrowrock Dam, Boise Project, Idaho.

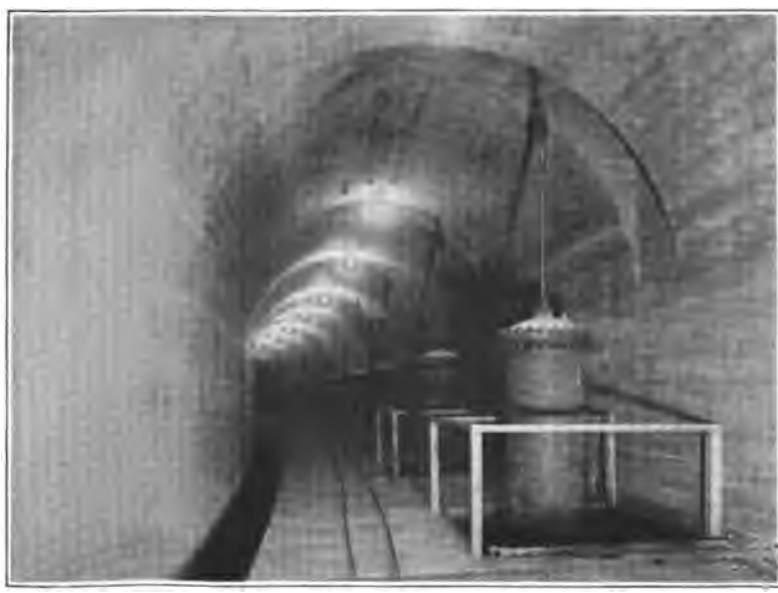


Plate VIII. B.

Operating cylinders for sluice gates, also portion of inspection gallery in Arrowrock Dam, Boise Project, Idaho.

Plate VIII. C.

A series of curved spillway sections near East Park Dam, Orland Project, California.

Plate VIII. D.

Erosion at lower toe of Mexican diversion dam on Rio Grande above El Paso, Texas.

provide a depression or low point of overflow at some little distance from the dam, so that the water of great floods may not be able to attack the foundations and wear away the supporting walls. As previously noted, it is absolutely essential that in the case of earthen structures the spillway be of such size and shape as to render it impossible for water ever to overflow the earthen banks; the margin of safety against overtopping by any probable flood must be large. Long-continued observations of river flow are showing that there is possibility of the occurrence of floods surpassing those recorded in previous years and that in these matters we cannot afford to take any chances, but must provide maximum flood openings.

Examples of spillways are given in the accompanying illustrations; that marked Pl. VIII. C shows a series of small, vertical curved dams which form the spillway for the East Park Reservoir on the Orland Project, California. The reason for adopting this shape was to give additional length to the spillway and to permit a larger volume of water to escape for a given increase of height than would have been practicable with a short straight overflow section. The form also gives additional strength to the work.

In Pl. XVIII. C is shown a similar spillway whose plan is rectangular in form, being arranged in this way to enable a closer automatic regulation of the height of water in the canal below. These and other spillways are of great importance in connection with various devices for regulation of river flow. They have their widest application on streams which are subject to rapid change of height or where floods may occur without warning.

Retarding Dams. A type of dam is being developed in which the spillway is the most essential feature because of the fact that the dam is built for the purpose of providing a safe outlet, in contradistinction to the fact that in the past the spillway has been built merely as an adjunct to the dam. In other words, retarding dams are constructed in a manner such as to hold back any sudden flood and force it to pass through a constricted opening or over a spillway with a limited capacity so that only a part of the flood can continue immediately down the river. Thus the flood is flattened out, removing the

dangerous features, and high water is prolonged, the flow continuing until the water which has temporarily accumulated behind the dam is able to pass through the restricted opening. The reservoir in this case is built not with the idea of holding the water for use, but only to provide temporary storage for a few days at most.

The important part played by retarding dams is being more and more appreciated as the results of study of them are made available. At first when it was assumed that the reservoir must or should be used for storing water for long periods of time, the conception of the retarding dam was ignored. Now, however, there is a better grasp of the subject and the value of this character of work is being made known on a true basis.[1]

FAILURES. A successful dam teaches few lessons. The fact that it stands shows that it has been strong enough to meet the conditions to which it has been exposed, but as to whether it is unnecessarily strong or is on the verge of failure no one can demonstrate. Whenever a dam fails, however, the loss is not only great, but incidentally the lesson to be learned is valuable. It is important, therefore, that each case of failure be studied and deductions made for guidance in other works. When compared with the number of successes the failures have been relatively small, but nevertheless they are deplorable through loss of life and property. The principal cause has been weakness of foundations or carelessness in making a water-tight joint under the dam. Next to this has been the overtopping of earth dams due to lack of provision of ample spillway capacity.

[1] See *Engineering News*, December 7, 1916, p. 1093, where in connection with the Miami, Ohio, flood prevention project it is stated:

"Not less important is the court's declaration that retarding dams combined with channel improvement furnish for the Miami Valley the only practicable and complete protection from floods; again there is opportunity for reflection by engineers. Flood prevention by reservoirs has been under a cloud—and for that matter is today under a cloud, and with good reason. The proposal to provide empty space for flood water and yet keep that space full of water for other use has proved very difficult to defend. But temporary impounding of flood waters, applied with patiently calculated precision and properly adjusted to the other variables of the problem can accomplish the best and cheapest flood control for the Miami Valley, for the Scioto Valley and perhaps for some other locations. This is a new fact."

In many cases the failures were the result of neglect after the structure was completed, such neglect being shown in lack of attention to the protection of the foundation or in permitting the spillway to be clogged. In the case, for example, of the Austin, Tex., Dam, the gradual undercutting at the base was generally known but was not given attention and in an extreme high water the dam slid forward into the hole excavated in part during a preceding flood. Such undermining of the toe is illustrated by the accompanying Pl. VIII. D of the diversion dam built by Mexicans above the city of El Paso, Tex., showing how the water flowing over the dam has cut away the protection at the lower side. This is probably a condition which has existed prior to many of the failures of dams, but by being concealed by standing water has not been given proper attention.

As shown by a study of dams which have failed, the weakest point in their construction or the one important matter which has been most frequently neglected is that of making a water-tight joint beneath the dam such as to prevent seepage under the structure. Over half of the recently recorded failures of dams have been caused directly by seepage through the foundations. All failures of reinforced concrete dams have been from the escape of water beneath the foundation and subsequent undermining. Many of these failures occur because cut-off walls were not carried deep enough, but in most cases there was little or no attempt to build cut-off walls and seepage occurred through fissured rock which was supposed to be sufficiently impervious to retain the water.

Next in importance is the construction of ample wasteways. Neglect of this precaution has resulted in an excessive head of water against the dam, with an accompanying pressure greater than that for which the structure was designed. The size of the wasteways was based upon an assumption as to volume of flood flow entirely too small, overlooking the fact that the floods which had actually been measured were by no means representative of the possibilities which might occur. In many instances the engineer feared to invite the ridicule of so-called "practical" men by building wasteways several times as large

as would have been necessary to pass the normal floods. Or to put it another way, he did not insist upon a factor of safety sufficiently great to take care of the extraordinary floods of a century.

Lack of proper care in the maintenance of the works is the cause of many disasters. For example, the failure of the hollow reinforced concrete dam of the city of Plattsburg, N. Y., was apparently due to the destruction of the foundations after several weeks of neglect. (See *Engineering News*, Vol. 75, June 8, 1916, page 1006.) In order to save expenses the public officials decided some time before the dam failed to do away with a city engineer as an expensive and unnecessary officer; thus apparently no one was responsible for the dam and little is known as to just what happened. The responsibility appears to rest on the city officials for disregarding the condition of the dam which was known to be leaking, and for attempting to plug up the holes which were giving warning of danger.

Careful investigation should be made as to the cause of each failure of water control or storage works and an analysis made of the causes. The results of such study have peculiar value as a guide in future construction and also as a means of relieving the apprehension of the public regarding dangers of such work. If it can be shown that in each case of failure there was some peculiar condition which need not be repeated, then the public mind may be set at rest to that extent. Without definite explanation there is apt to be a blind, unreasoning prejudice against work of this kind. Reference should be made to the action of the Conservancy Court in connection with the Miami, Ohio, Flood Protection Project as noted in *Engineering News*, December 7, 1916, p. 1093, where it is stated:

"Earth Dams are safe. The judges in the Miami case carefully and deliberately state their conviction of this fact. They reject the searching and persistent criticism of such dams, which the opposition put forward. Their opinion, formed after hearing elaborate evidence on every possible phase of this subject, is a salutary lesson to many an engineer.

"Bridges are safe, though some bridges have failed. Buildings are safe, though wretched design and bad work made many a wreck.

Dams are safe, though quackery and incompetence and neglect have brought about many a washout.

"The judges did not ask: May not a weak dam fail. They were willing to venture their own lives and the lives and property of their neighbors on the assumption that good dams would be built. And assuming good dams, they declared that the dams would be safe and of sufficient strength to sustain at all times any burden that may be placed upon them by impounded water. Many an engineer can study with profit this calm and deliberate statement made by laymen after weighing the merits of affirmative and negative in a lengthy battle of fact and opinion."

The literature on the construction of dams is quite voluminous—notably the articles in the technical journals and in the transactions or proceedings of the Engineering Societies of various countries. One of the most complete statements is a treatise by Edward Wegmann[1] in which he discusses the distribution of pressure and gives practical profits, with descriptions of important dams throughout the world, also an excellent bibliography.

[1] Wegmann, Edward, C. E., "The Design and Construction of Dams, including Masonry, Earth, Rock-fill, Timber, and Steel Structures, also the Principal Type of Movable Dams," John Wiley & Sons, six editions.

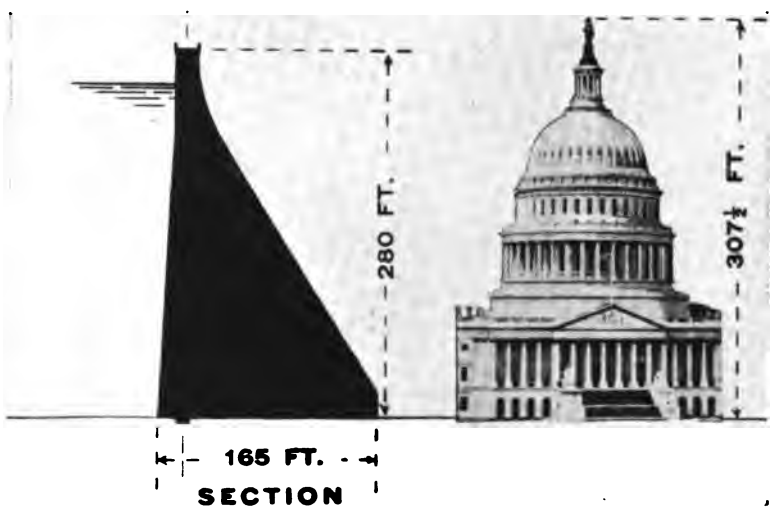


Figure 5. Comparison of Roosevelt Dam with Capitol at Washington.

CHAPTER IX

NOTABLE WORKS

Reclamation Service. The great works which are yet to be built and operated for the benefit of mankind are best advocated by the showing of what has been accomplished. The achievement of the national government in conserving flood or waste waters and in converting parts of the desert into prosperous farms is both proof and prophecy of what can and should be done on a larger scale. For this reason space may well be given here to a brief description of some of the larger dams built by the United States Reclamation Service. These have been made possible by the use of the data already described; they embody many of the principles which have been the subject of research such as noted in previous pages. They serve to demonstrate the fact that other storage works may be built safely and efficiently in many different localities, using an almost infinite variety of materials and methods. Among the best known of these are the Roosevelt, notable for its size; the Shoshone, for some time the highest dam in the world; the Pathfinder, built in its granite gorge; the Arrowrock, now the highest dam; the Elephant Butte, remarkable for its straight gravity section; and others of earth and concrete each adapted to meet the surrounding limitations.

Before entering into these engineering details, it is desirable to give a note of explanation of the United States Reclamation Service. This organization, under the Secretary of the Interior of the United States, was created by Act of Congress, June 17, 1902, for the purpose of survey, examination, construction, and operation of works for the reclamation by irrigation of arid and semiarid lands. Funds were provided in the act by setting aside the proceeds of the disposal of public lands which from 1902 to 1919 aggregated over $100,000,000.

This amount has been supplemented by an additional loan of $20,000,000—all of which has been spent in works for conservation of water by storage and the distribution of the stored supply in the western part of the United States.

The necessity for this law arose from the fact that the western two-fifths of the United States consists in great part of public land. The conditions of aridity are such that only a very small portion of this land can be utilized for agriculture. Attempts made by individuals and organizations to irrigate the lands, although successful from an agricultural standpoint and from that of the development of the country, were not profitable to the investor, hence the development and the use of the resources of the West were not progressing rapidly. It became appreciated about 1900 that further progress could not be expected without direct effort on the part of the federal government, the owner of the great body of the arid public lands. The objection to making direct appropriations for improving these lands was met by the ingenious plan proposed by the late Senator, then Representative from Nevada, Francis G. Newlands, to the effect that money derived from the disposal of portions of the land should be used in reclaiming other portions.

The Reclamation Service was an outgrowth of the work of the United States Geological Survey. The latter bureau was authorized by Congress in March, 1888, to investigate the extent to which the arid region might be reclaimed, this action being taken largely through the effort of the then director, John Wesley Powell. The investigations were made by what was known as the Hydrographic Branch, measurements of water supply in many streams being begun and also surveys of possible reservoir sites. The information thus obtained and widely diffused laid the foundations for a presentation of the needs and opportunities of water conservation and furnished the facts for action by Congress, taken in accordance with the recommendation of President Theodore Roosevelt in his first message in 1901. As organized immediately on the passage of the Act of June 17, 1902, the work was under a chief engineer, F. H. Newell, who continued in charge, reporting to the director of the Geological Survey until 1907, when the service became a

separate bureau and the chief engineer was then made director, reporting to the Secretary of the Interior.

Under the original organization, plans were prepared during the years 1902 to 1907 for works whose completion has required all of the funds which would be available from the proceeds of the disposal of public lands for a decade or more. These plans were so drawn as to permit expansion to the full limit of the available water supply in each locality. The work was undertaken in such manner as to enable completed portions of each project to be utilized before all parts were finished. It was also considered wise to start work on a broad basis in a number of localities rather than to concentrate it in a few places, because by so doing a more nearly normal growth of each project was possible. This line of procedure was in contrast to the attempts made by private investors to complete one large project and then operate it as a whole without having had the advantage of experience acquired through the slow growth of the component parts. Most of the works thus planned from 1902 to 1907 have been brought to a degree of completion such that a large part of the land is being utilized.

The principal works are those for storage of flood or waste waters and for conducting the waters thus made available from the natural streams to the lands to be watered. Besides the storage dams, many diversion dams have been built in the rivers, turning the water into large canals which divide and subdivide into smaller distributaries or laterals leading to each farm. In these canals and at each outlet, gates are provided to control the water; there are also flumes, pipe lines, bridges, culverts, as well as almost innumerable other structures, each requiring engineering skill in its construction and maintenance.

Storage Works. For the purpose of storing flood water over fifty noteworthy dams have been built by the Reclamation Service. They are listed and described in the annual reports of that bureau and are discussed at some length in several recently issued books[1] and engineering publications. In the

[1] Davis, Arthur Powell, "Irrigation Works Constructed by the United States Government," John Wiley & Sons, New York, 1917, pp. 413, illustrated.

James, George Wharton, "Reclaiming the Arid West. The Story of the

Plate IX. A.

Sheep grazing along canal in vicinity of Huntley, Montana, illustrating how they may be used to keep down the weeds on canal banks.

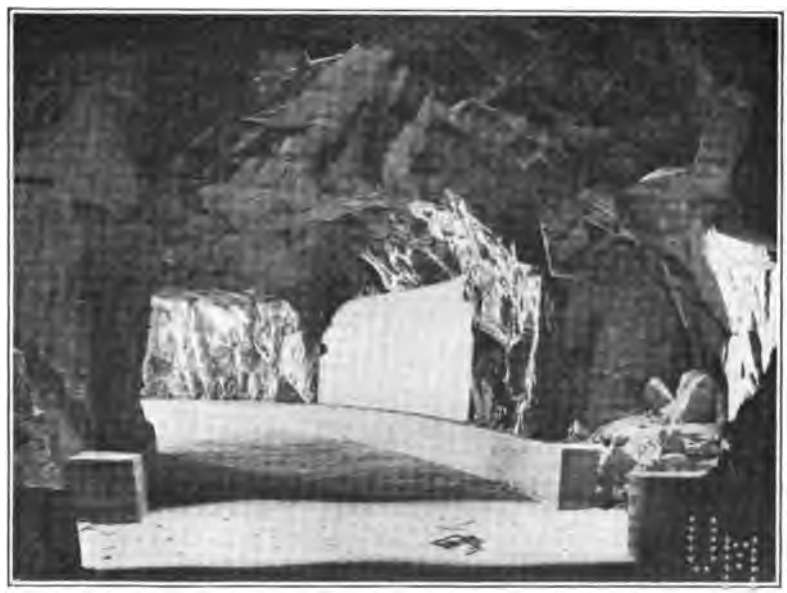


Plate IX. B.

Tunnel for diversion of North Platte River at Pathfinder Dam, Wyoming.

Plate IX. C.
Shoshone Dam, Wyoming, as seen from water side before completion.

Plate IX. D.
Part of reservoir created by Shoshone Dam, Wyoming, with wagon road around side of reservoir leading to Yellowstone National Park.

aggregate, it appears that upwards of 20,000,000 cubic yards of earth, rock and concrete have been handled in the construction of these. They range in height from 50 to 350 feet and in length along the crest from 500 to over 7,000 feet. The reservoirs created by these dams have an area of from about 1,000 acres up to 40,000 acres and a capacity of from 10,000 to over a million acre-feet. They thus cover a wide range of conditions and afford examples, for future emulation, of methods successfully adopted in meeting and overcoming various difficulties.

The wide diversity in quantity of run-off per square mile available for storage in various reservoirs is notable. This is partly due to the great variation of yield, from year to year, of the arid region streams. The run-off of any one year or the mean of a few years may differ widely from the average of a 10- or 20-year period. The principal reason, however, for the great diversity in quantity of water which may be held is that some of the reservoirs are near the headwaters with catchment areas on which is a heavy rain- and snowfall while others are so located as to receive the meager and erratic drainage from a large extent of low-lying, arid land.

Cost and Value. In connection with these reservoirs, the most interesting item, perhaps, is the cost as compared with the benefits received directly and indirectly. In the case of the Roosevelt Reservoir in Arizona, where stored water has great value, the capacity for storage or quantity which may be had each year has cost at the rate of $7.76 per acre-foot. The lowest expenditures are naturally in the case of preëxisting lakes which have been utilized, this being for Lake Tahoe only $1 per acre-foot. The highest cost of stored water is for the smaller artificial reservoirs, the large expenditure upon which has been justified by some special circumstance.

In considering the cost and value of any reservoir for conserving water, it is necessary to make allowance for losses. It is obvious that the full amount of water delivered to a reservoir cannot be depended upon as, under ordinary conditions, it is impossible to draw out as much water as has been put in. The

United States Reclamation Service," Dodd, Mead & Co., New York, 1917, pp. 411, illustrated.

losses are of two principal kinds: first, that by evaporation from the surface; and second, that by seepage from the bottom and sides. The seepage loss may be reduced and in time may become negligible, but the evaporation losses are practically permanent (see page 65), and although the quantity varies from season to season, yet it is always a considerable part of the water received. This amount may be measured by apparatus similar to that described on page 70, a standard evaporation pan being placed on or as near the surface of the water in the reservoir as possible and maintained at the same temperature.

Knowing the average amount of water available each year for a reservoir and its cubical contents, it might be supposed that the problem as to the amount to be delivered from the reservoir would be a simple arithmetical computation. This is not always the case because of the fact that the water flowing into the reservoir varies in quantity from season to season and a statement of averages may be quite misleading. Moreover, the demand upon the reservoir is not constant and may occur at times when the basin is partly empty, and then it cannot be fully met. The capability of the reservoir to deliver water or what may be called its working capacity can be ascertained only by making certain assumptions followed by somewhat elaborate computations based upon these.

In making these estimates of the working capacity of a reservoir, it is desirable to take into consideration separately each day or period of a week or ten days, and for this period the probable inflow during that time, deducting the probable losses, and from this to compute the total amount of water left in the reservoir at the end of this day or week. If the reservoir is full to overflowing there cannot, of course, be any added accumulation. At such time also the losses by evaporation and seepage are at a maximum. If, on the contrary, the reservoir is nearly or quite empty, the losses will be at the minimum and the reservoir can probably hold all of the water which flows in during that time.

By these computations there is built up a series of estimates which follow as closely as possible the fluctuations and which take account of conditions which are not revealed if reliance is

placed on seasonal or annual averages. For example, if it is assumed that during the year 100,000 acre-feet are received in the reservoir and the loss by evaporation and seepage is 10,000 acre-feet, then there should be available 90,000 acre-feet. This amount can be held in a reservoir of a capacity of, say, 50,000 acre-feet if drawn out steadily during the irrigation season and at the same time replenished by summer floods. As a matter of fact, however, the greater part of this 100,000 acre-feet might occur early in the season before it was needed for irrigation and would thus pass through the reservoir, bringing in great quantities of silt and being unavailable at the time when most needed. Moreover, the losses by evaporation would be greatly affected by the time at which the water filled the reservoir. For these and other reasons it is important that these shorter periods be used in our computations in order that we may properly take into account the fluctuations, time of occurrence and uses of the water.

Roosevelt Reservoir. This is one of the best-known and most important of the works built by the government under the terms of the Reclamation Act. The structure shown in Pls. I. B and II. C is about 70 miles east of Phoenix, the capital of Arizona, and consists of a rubble masonry, curved dam located in the river canyon with a height of 280 feet and a length on the crest of 1,125 feet. The relative height of the dam as compared with the capitol at Washington, D. C., is shown on Fig. 5.

The reservoir formed by the dam has a capacity of 1,365,000 acre-feet and covers 16,800 acres. It was first filled in April, 1915, over four years after the completion of the dam. A series of unusual storms then caused the stored water to overflow the spillways, as shown in Pl. II. C. The excess flood was disposed of without harmful effect, leaving in storage sufficient to insure a supply for several years. The water is utilized to irrigate nearly 200,000 acres of land in the vicinity of Phoenix. The stream flow records, conducted for twenty-five years, show an extremely erratic run-off and indicate that the reservoir may be filled by floods at irregular periods with an occasional series of low years, at the end of which time it may be nearly empty, causing temporary shortage of water. This will then necessi-

tate strict economy in irrigation. Such shortage may be a benefit rather than an injury, as it will tend to reduce the waste and prevent destruction of the lowlands by overirrigation.

As an incidental benefit in the conservation of this flood water is the creation of hydro-electric power. As the water is drawn from behind the dam for conveyance down the river to the arid lands a large amount of power is generated, the quantity depending upon the height of water in the reservoir and the volume turned out. There are four hydro-electric units, with capacities varying from 1,000 to 5,000 kilowatts. A portion of this power is used for pumping, but the greater part is sold and the returns credited to the cost of the plant.

The stored water when released passes down the canyons for about 50 miles to the Granite Reef diversion dam, where it is forced to flow into canal systems on the north and south banks of the river. These include over 800 miles of main canals and laterals bringing water to nearly 5,000 farms. Along these canals at several points hydro-electric plants have been built to utilize the falls which have been necessary because of the slope of the country.

The total investment in this complete system of water conservation by storage and distribution of water and power is approximately $11,500,000. This will be repaid to the United States by annual installments from the farmers whose lands are benefited. Although the system has hardly been completed, yet crops of a gross value of over $18,000,000 were harvested in 1918 and the increase of taxable property in the community due to the building of the works has been at least five times the original cost.

The area supplied with water from the Roosevelt Reservoir is known as the Salt River Project. The characteristic feature of this project, which distinguishes it from other enterprises of the Reclamation Service, is the warm climate which, where water is obtainable, renders crop production possible throughout the greater part of the year. The number and value of the crops justify a relatively large expenditure for the storage of water and necessitate a high degree of economy in its use. In this respect the project is similar to the costly private works

in southern California, where water for irrigation has its greatest value as compared with any other part of the United States, and where during each succeeding decade larger and larger sums are being expended in conserving the scanty supply.

The engineering problems are those which grow out of the necessity of attempting to control a river which is not only erratic in its floods, but which apparently has a cycle of wet and dry years, more distinctly marked in this case than has been made apparent on other rivers on which reclamation works have been built. This results in the necessity of considering storage not merely for the current year, but with relation to the series of dry years which have been known to exist, following seasons during which floods have occurred with more or less regularity. Consideration has been given to the question as to whether storage should be provided adequate only to handle the floods which occur during the low years, or whether the expense would be justified of building a reservoir capable of holding larger floods, and with the probability that it would not be filled during the succession of low years. In working out any plan it was necessary to meet certain conditions of human origin, namely, the existence of irrigating canals built by the irrigators acting individually or in coöperation, or by investors hoping to secure a profit on the sale of water rights and of lands.

Salt River Valley includes the lands in southern Arizona, extending from the point where Salt River emerges from the mountains near the mouth of Verde River, its principal tributary, to the locality where Salt River flows into the Gila, a tributary of Colorado River. Irrigation was carried on in this valley in prehistoric times by ancient peoples whose canal lines have been nearly obliterated. The river has a decided fall, so that water can be diverted at almost any point and carried diagonally away from the stream, covering considerable land within a short distance from the point of diversion.

The first use of water for irrigation by white men was in 1868, through the Salt River Valley Canal. From this time on the building of new works continued rapidly until the combined capacity of the canals was far in excess of the normal low water

flow of the river, their construction having been induced by a superficial consideration of the series of years of abnormally high run-off between 1888 and 1897. Following that period the reverse occurred, and for over six years general drought conditions prevailed, resulting in the destruction of valuable orchards, vineyards and alfalfa fields, stimulating active efforts on the part of the inhabitants of the valley to secure the construction of storage reservoirs.

The original plan of the Reclamation Service in accordance with the then needs was simply to build a reservoir, leaving the companies and associations operating the canals in the valley to enlarge and extend them later as needed for the delivery of additional water supply. A great flood in 1905, however, destroyed the diversion dam and otherwise injured the works of the Arizona Water Company, which controlled all the canals on the north side of Salt River. The inability of the company to promptly repair the works led to their purchase by the Reclamation Service and to the subsequent reconstruction of the diversion and distribution system.

As worked out, the Salt River Project includes the largest hydro-economic system practicable: viz., a storage reservoir, a large concrete diverting dam, with sluices and headworks on each side of the river, a complete system of canals and laterals to cover over 200,000 acres of land, and a power plant at the Roosevelt Dam with a transmission line to bring the electric power to the valley below, where it joins other power developments on the canals, and is used in pumping underground waters and for similar purposes.

PATHFINDER. The Pathfinder Dam and reservoir on North Platte River in central Wyoming is of particular interest as illustrative of excellent natural conditions for conservation of water by storage and of certain problems which arise in connection with such an enterprise. The dam is of simple gravity section, built of granite quarried from the immediate vicinity. The river at the point has cut its way through a mass of granite and unlike many other gorges in the arid region the ancient river channel has not been deeply buried. Thus it only required excavation of the loose debris to a depth of not to exceed ten

feet to reach the solid granite bottom. The gorge itself in which the dam is built is narrow, and with vertical walls, as shown in Pl. VI. A. The diversion of the river was easily accomplished through a tunnel located on the north or right hand side looking downstream. A view of the tunnel is shown on Pl. IX. B. In this tunnel have been placed gates for controlling the outflow of the reservoir. During construction the river was diverted through this tunnel and when the dam was partly completed the tunnel gates were closed, enabling flood water to be held in the reservoir.

A short distance upstream the valley widens and affords space for a storage reservoir of over 22,000 acres, in which nearly the entire discharge of the river can be held from the time of the spring floods to the dry period of summer. After the completion of the dam it was found advisable to build a higher outlet than the one originally provided, on account of the excessive erosion of the controlling device under the high heads when operating with the reservoir nearly full. As completed the masonry dam is 218 feet high and 432 feet in length along the crest. A short distance to the south of the dam a dyke has been built to raise the level of the reservoir and prevent water overflowing a gravel ridge which extends south from the granite gorge above described. This ridge closes what is apparently an ancient channel or depression.

The stored water held in this reservoir in central Wyoming is permitted to escape as needed and is recaptured by what is known as the Whalen diversion dam, over 150 miles downstream and at the head of the Interstate Canal in eastern Wyoming. This has a capacity of 1,400 cubic feet per second, is nearly 100 miles long, extends into western Nebraska and serves about 130,000 acres in the states of Wyoming and Nebraska. On the opposite or south side of the river is under construction a similar large canal known as the Ft. Laramie, intended to water 100,000 acres. Besides supplying the two large government canals with water for the 230,000 acres, above noted, the Pathfinder Reservoir provides water in ordinary years to supplement the supply of a number of private older canals along the river. The cost of the reservoir is, in round numbers,

$2,500,000, and of the canal system nearly an equal amount. In 1918 when only about 85,000 acres were irrigated, the annual crop value reached $3,000,000. With the increase in area and with the more thorough farming methods, the returns are increasing rapidly.

When the United States entered this field a large number of small canals had been built taking water from the river, some in Wyoming but most of them in Nebraska, so that in August, in years of low run-off, the stream was nearly dry at the state line, and in normal years most of the canals in Nebraska were short of water in the late summer. The government investigations began with a search for reservoir sites, resulting in the discovery of several possible locations. The one finally selected is that about fifty miles west of Casper, Wyo., where the reservoir, formed by the building of the Pathfinder Dam, has a capacity of 1,070,000 acre-feet, a magnitude sufficient to provide storage for irrigation purposes of all the unappropriated supply of normal years, and to hold a large reserve from the years of heavy run-off for use in years of drought.

The entire supply received by the Interstate Canal is used during the summer for the direct irrigation of the lands under it. In the spring and autumn, when less water is used, the surplus capacity is employed to convey water to two reservoirs that have been constructed in the valley, beginning about 100 miles below the headworks of the canal, Lake Alice, with capacity of 11,400 acre-feet and Lake Minatare, with a capacity of about 67,000 acre-feet. These reservoirs enable the main canal to bring water to a much larger area than it could otherwise supply, and also furnish insurance against drought to the lands under them. Without them the cultivated lands might be left waterless in the event of a break in the main canal, the liability to which increases with its length.

Shoshone. In contrast to the massive dimensions of the Roosevelt and Pathfinder dams, but similar in having a curved plan, is the extremely high and relatively thin concrete dam on Shoshone River in Wyoming, east of Yellowstone National Park, shown from the upstream side in Pl. IX. C. This, when built, was reputed to be the highest in the world, the crest being over

328 feet above bedrock, and only 200 feet long, the dam containing 78,576 cubic yards of material. The canyon at this point is very narrow, as shown in Pl. IX. C. Above the canyon the valley spreads out, permitting the formation of a lake which when full has a surface area of 6,600 acres and a capacity of 456,600 acre-feet.

At a point about 16 miles below the storage dam, the water is diverted by a low overflow dam into what is known as Corbett Tunnel, 17,355 feet in length, which delivers it to the main canal, which has a capacity of approximately 1,000 second-feet and a length of 18 miles. This in turn distributes water to over 380 miles of smaller distributaries, providing water for upwards of 150,000 acres, of which, however, only a portion is at present under cultivation—the canal system being constructed well ahead of farm developments. On these lands, hay and grain are produced and small tracts are devoted to vegetables. Alfalfa is the principal crop here as elsewhere on the irrigation projects, exceeding all others both in area planted and in value.

The reservoir created by the Shoshone Dam is in the line of direct travel from the town of Cody, Wyo., to the Yellowstone National Park, and hence it has been necessary to build roads around the margin of the water to replace those submerged. The country in which these are located is quite rough and in places the roadway passes through tunnels, as shown in Pl. IX. D. As finally built, a few feet above the level of the reservoir, the road forms one of the most attractive approaches to the park.

Arrowrock. The highest storage dam in the world, that on the Boise River in Idaho, is a concrete structure, curved in form and with relatively thin section. It rises 350 feet above the lowest point of base and measures 1,100 feet along the crest. The storage provided is small compared to that of other large dams because of the fact that the valley does not widen out above the dam site but continues as a narrow gorge. The locality chosen was, however, the best point available for holding the floods of the stream and the value of water is such as to justify the larger expenditure per acre-foot stored than in the case of some of the other dams. The cost per acre-foot capacity is

approximately $25, as compared with less than $3 for the Roosevelt Dam and less than $2 for the Pathfinder.

The accompanying view, Pl. X. A, was taken when the dam was approaching completion and shows in the background a portion of the reservoir, also near the center of the dam the water issuing from the highest row of outlets. On the extreme left is the spillway, formed by making a narrow cut in the hillside. The water stored here is allowed to flow down the river as needed and at a point about twelve miles below is taken out by a lower dam into the head of a large canal. This serves not only certain of the agricultural lands but also carries a large part of the flood water to a depression out on the plain known as Deer Flat Reservoir, where it can be held to meet later needs. By utilizing the Arrowrock Reservoir in the narrow river valley to regulate the floods as well as to store a part of the water, it is possible to so control the stream as to make more largely available the Deer Flat Reservoir and to conserve the greater part of the floods which otherwise run to waste.

Among the many notable features of this dam may be mentioned the method of discharging the stored water. Instead of having one or two large outlets built in tunnels through the rocky walls, the plan has been adopted of providing a series of outlets directly through the dam and at various heights. The problem has been to discharge the water at necessary times in such a way as to overcome the destructive energy of the water as it issues.

Flood flows of such magnitude that they cannot be controlled by various valves in the dam are taken care of by the spillway located at the extreme left, Pl. X. A. This is regulated by a rolling device which allows the flood to pass over the spillway or which can be raised to maintain the desired water level. The operation is automatic, the rolls falling and permitting a larger and larger volume to escape as the flood rises or as the flow declines the discharge is automatically checked. By the device installed, floods of 40,000 second-feet can be handled and the flow regulated from 1 second-foot to 10 second-feet (*Engineering Record*, September 30, 1916, p. 409).

ELEPHANT BUTTE. This structure is of interstate and inter-

Plate X. A.
Arrowrock Dam, Boise Project, Idaho, water issuing from five openings in the upper row.

Plate X. B.
Elephant Butte Dam, New Mexico, under construction.

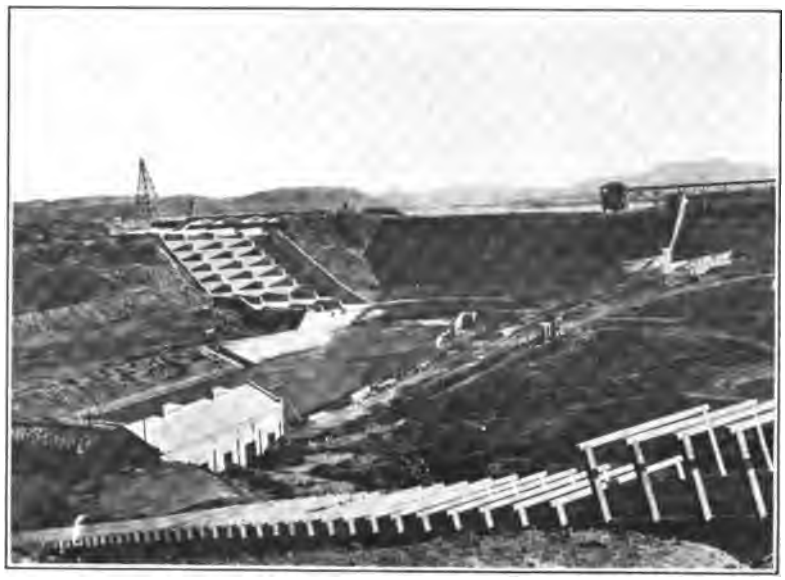


Plate X. C.
Earth dam on Carson River, Nevada.

Plate X. D.
Lake Keechelus, Washington, one of three large lakes converted into reservoirs at head of Yakima River. Temporary wooded crib dam above site of permanent earth dam.

national interest in that it stores the water of the Rio Grande, which rises in Colorado, flows in a southerly direction through New Mexico, forms a portion of the boundary between New Mexico and Texas and finally forms the international boundary for several hundred miles between the states of Texas and Chihuahua, Coahuila, and Tamaulipas, in the Republic of Mexico. The water stored in the reservoir is to irrigate land in New Mexico and Texas, 60,000 acre-feet being set apart to be distributed to Mexico in recognition of prior rights and of international comity. The dam, unlike the Roosevelt, Arrowrock, and other large storage works built by the Reclamation Service, is perfectly straight in plan, the width of the valley being too great to utilize economically the curved form. In vertical section it is somewhat similar to the Roosevelt Dam, the extreme height is 300 feet, as contrasted with 280 feet on the latter, and the cubical contents are nearly double.

The reservoir created by the dam is one of the largest in the world, being nearly 40 miles in length and contains over 2,600,000 acre-feet. The necessity for this large storage capacity arises because of the large fluctuations of the river from year to year, the maximum annual flow being about 2,422,000 acre-feet and the minimum 200,700. It is necessary to provide storage to hold the high floods so that some of the water may be carried over the years of drought. Another necessity for having great reservoir capacity lies in the fact that a large amount of silt is brought down by the river and left in the still waters of the artificial lake. The size of the reservoir will enable this silt to accumulate for many years without material injury.

The stored water is discharged through numerous sluices, as shown in Pl. X. B, which gives a view of the dam as it was approaching completion. In the background is to be seen the mass of black basalt known as Elephant Butte, rising through the sedimentary rocks and forming a striking landmark.

Lake Tahoe. In marked contrast to the costly works just described is the low, easily built dam which regulates the outflow from this natural lake, one of the largest and most economically operated of the natural reservoirs in the arid west. The lake, partly in California and partly in Nevada, is remarkable

for its high altitude, over 6,000 feet, and for the peculiar beauty of the surrounding mountains and forests, making it very attractive for summer residence. The use of the lake for storage has been governed to a large degree by æsthetic considerations as it was not desired to raise the level beyond a certain fixed point to avoid flooding the lands along the shore valuable for residence, nor was it practicable to lower the water more than a few feet because of possible interference with navigation by the small craft which form the principal means of conveyance to and from the hotels and houses lining the shores. It has been possible within these narrow limits to work out a scheme of control such as to hold the greater part of the spring freshets which reach the lake and not permit any considerable amount of water to flow to waste.

A view of the lake is given in Pl. I. A, illustrating the general topography. The outlet is a relatively small river, the Truckee, which, flowing north and continuing for a time in California, turns easterly and with rapid descent enters the eastern edge of Nevada, where it soon disappears in Pyramid or Winnemucca lakes, these being shrunken remnants of the ancient fresh water body known as Lake Lahontan. To regulate the outflow of Tahoe into Truckee River, it has been necessary merely to build a low dam, originally of logs, similar to that shown on Pl. X. D, but less elaborate. This early structure has been replaced by one of concrete, founded mainly on the river gravel, and provided with gates of sufficient width to permit drawing down the lake during the few days of extreme demand for water in the lower valleys in Nevada.

In its course in California, several water power plants, mainly for electric transmission, have been built, and farther down in Nevada a number of private irrigation canals take most of the water from the river. Still lower and a few miles above the lakes or sinks into which the river disappeared when in a state of nature, a large canal, Pl. XII. C, built by the United States Reclamation Service, takes the remaining water to the adjacent desert lands and in flood time to a reservoir on Carson River. The problems of water conservation and of distribution are thus quite complicated. Storage in Lake Tahoe of the excess waters

of spring is relatively simple, except as modified by the requirements of the summer residents. In letting out this water, however, provision must be made for the rights asserted by the officials of the two states concerned and by the owners of the power plants and of the older irrigation works whose claims to the water are somewhat indefinite. The lower storage on Carson River aids in economically handling available water, but the floods and the return water from the old canals add various complications.

LAHONTAN. The low-lying reservoir on Carson River formed by this dam presents many interesting features in connection with the solving of problems of saving waste water on the lower reaches of torrential streams. The ideal condition in storage is to hold the water at as high a point as practicable in the mountains, as is done in the case of Lake Tahoe, situated at the head of Truckee River. On the Carson River, which rises in the high valleys immediately south of the Truckee, are numerous reservoir sites. The first question which naturally occurs to the student is as to why storage works have not been built there instead of at the place selected. This might have been done had it not been for certain artificial limitations set by the manner in which the country has developed and the adverse rights which have attached to the use of water.

The streams which go to make up the Carson River rise on the east side of the Sierra Nevada Mountains in an area included within the boundaries of the state of California. The reservoir sites, therefore, which are needed for impounding the water for use in Nevada are in the adjacent state. The condition is similar to that which exists at Lake Tahoe, except that the line between the two states has been drawn through Lake Tahoe, dividing its water surface between the two states. The questions of the rights to the use of the water of the tributaries of the Carson River have not been settled as between the two states and the various claimants residing therein. It is probable that many years of expensive litigation must ensue before these rights are fully determined. In the meantime it has seemed unwise to wait for decisions on these points inasmuch as apparently, in

whatever manner the questions are decided, there will be a considerable volume of flood water coming down the main stream each year.

The Lahontan Reservoir has been built to conserve the water which escapes from the irrigated lands in the valley of the Carson River and particularly the erratic floods which may occur at any time, but particularly in the spring. Its position far down the main stream near the edge of the desert enables this to be done, and also permits it to be used in connection with the excess water of Truckee River, as noted above. Hence it serves the purpose of taking care of much of the water of both rivers which otherwise would have been lost in the lakes or sinks into which during past ages they have disappeared.

The dam shown on Pl. X. C is notable for the large size and massive character of the spillways built at each end of the earthen structure. These were necessitated by the fact that the underlying rocks are quite soft and easily eroded. They are of such doubtful character that it was not deemed wise to attempt to build a high masonry dam upon the site nor was there sufficient hard material near by to justify making a concrete structure. In fact, in order to secure suitable earth it was necessary to make careful selection from among the materials in the vicinity. The dam itself has been made of ample dimensions so as to distribute the weight and to completely cover the foundation.

The Lahontan Dam being of earth placed in the path of the floods and in a locality where the native rock is easily worn away, it has been necessary to take somewhat extraordinary precautions against overflow of the main structure and to break up or neutralize the destructive forces of the waters which may escape over the spillway. This has been done by so arranging that the water which escapes around the ends of the dam shall fall, not in one continuous body, but shall be dropped from step to step until finally it arrives at the level of the river. Here, instead of being turned directly downstream, it is given a course parallel to the axis of the dam. The water, brought in a curved path down this series of steps forming one spillway, and finally reaching the lowest point, encounters directly in its

path an equal and similar volume which has come down the other spillway. Thus we have two equal and opposing volumes of water expending their destructive energies on each other instead of upon the easily eroded native rock. This action takes place in a massive cement-lined basin and the tumultuous water, overflowing on the lower side, passes down the river with its destructive energy greatly reduced.

This whole system, beginning with Lake Tahoe and ending with the distribution below Carson Dam, is illustrative of various methods of overcoming difficulties which at first seemed almost insurmountable, these arising not merely from physical conditions but from legal or artificial restrictions set by state lines and by imperfect or indefinite water laws.

STRAWBERRY VALLEY. An earthen dam affording interesting contrasts with the one just described is that built at the outlet of Strawberry Valley near the crest of the Wasatch Mountains of Utah. Strawberry Creek is a tributary of the Duchesne River, whose waters flow into the Green River and through this into Colorado River. On the west side of the range are small streams which flow into the interior valleys of Utah, their water being used in part for irrigation, the remainder being lost by evaporation, mainly in Great Salt Lake. In order to supplement the flow of these streams and to increase the area of land irrigated in Utah Valley, a tunnel about three miles long was built to carry water from Strawberry Valley westerly. An adequate supply has been secured by building a dam to hold back the flood flow of Strawberry Creek, thus creating a lake with an area of 8,200 acres and a capacity of 250,000 acre-feet.

The dam is an earth fill with reinforced concrete core 72 feet high, with a crest length of 488 feet. Being near the head of a relatively small stream it has not been necessary to provide spillways as elaborate as those of the Lahontan Dam and the adjacent rock is sufficiently strong to withstand the erosion which takes place during the brief floods. A view of the dam when under construction is given in Pl. VI. D. In this view the top of the core wall can be seen projecting above the two unfinished banks of earth between which is an area to be filled in, completely covering the concrete wall. On the hill above the

dam and marking the upper limit of high water in the reservoir are shown the shops and mixing plant.

YAKIMA LAKES. Somewhat similar to Lake Tahoe are the Yakima Lakes in the state of Washington. These are a group of three large and several small lakes on the east side of the Cascade Range at the head of Yakima River. The regulation of these was undertaken before the land around their borders was largely utilized for summer residents; hence it was possible to provide a greater range of height of water than in the case of Lake Tahoe, drawing it down below the natural level and allowing it to fill up to a point above the former height. These lakes are known as Keechelus, Kachess and Clealum. The Reclamation Service has built dams of earth across the valley at the lower end of each of these lakes. These earthen dams, as a rule, have been built with core walls of puddled material. The outlets of the lakes have been lowered by means of tunnels or deep excavations across the line of the dam. A view of the temporary or preliminary timber dam at the outlet of Lake Keechelus is shown in Pl. X. D. The final or permanent earth dam has been built immediately below this point and raises the surface of the water about 40 feet.

The water stored in these upper reservoirs is utilized in supplying lands along the Yakima River, it being the intention to hold practically all of the flood flow and bring about development of the arid lands to the limit of the supply thus made available. The principal canal system depending upon these reservoirs is that known as Sunnyside, the head of which is shown in Pl. XI. A. There are about 80,000 acres under this canal; the land being at a low altitude and with warm climate produces very valuable crops—the gross return in 1918 being about $7,000,000.

DEER FLAT RESERVOIR. In contrast with the mountain storage in Roosevelt, Tahoe, the Yakima Lakes and other reservoirs near the headwaters are the conservation works built in the low, open valleys such as the Lahontan. Here, in such valleys, the conditions for storage are rarely favorable because of the long length of dams necessary to inclose the depression and the broad expanse of relatively shallow water exposed to evapora-

tion. In the case of the Deer Flat Reservoir in southern Idaho, the land utilized for water storage was originally devoted largely to agriculture. The broad valley or depression selected between the low, rolling hills, to the eye at least, does not offer any particular advantage as a reservoir site. However, careful survey disclosed the fact that a reservoir could be made by building several low, earthen dams, as illustrated in Pl. XI. B.

One of these earth dams, 70 feet high, is 4,000 feet long, the other, 40 feet high, is 7,200 feet long, each containing over a million cubic yards of earth. They are faced on the water side with heavy gravel obtained in the vicinity, no large rock being available. A somewhat noteworthy experiment is being made in that the embankments were widened at the top to a total of from 60 to 70 feet, by dumping gravel from cars on the 3 to 1 water slope. This was allowed to lie at its natural angle of repose. As the water surface rises and falls, the wave action works this gravel gradually down the slope. The cutting has, however, been much slower than expected, the top width after several years being but slightly reduced.

Belle Fourche. Similar in some respects to the Deer Flat Reservoir is that of the Belle Fourche Project created in the broad valley of Owl Creek, South Dakota, by building an earth dam 6,200 feet long and containing 1,600,000 cubic yards. In its relatively thin cross section and great height this is one of the notable earthworks, the crest being 115 feet above its base and the side slopes two feet horizontal to one foot vertical. To defend the dam from wave action it was deemed desirable to cover the water side of the embankment with large concrete blocks, as shown in Pl. XI. C.

In building this dam the only material available in the vicinity was found to be adobe clay. This material was handled with difficulty unless the moisture contents were just right. When wet the adobe is sticky and refractory and when dry it bakes into hard masses or lumps and pulverizes into a fine powder which forms dense clouds of dust. Moreover, it contains in some places a considerable amount of gypsum, which is quite readily soluble, so that care was necessary to make selection of

the layers which were nearly free from this objectionable material.

The water collected in the reservoirs is that from the occasional storms which occur in the drainage basin of Owl Creek, but the chief source of supply is that obtained from a feed canal from Belle Fourche River. Water is diverted from this stream by means of a dam located about two miles below the town of Belle Fourche, S. D., the canal leading from this point being 6.5 miles in length and having a capacity of 1,600 cubic feet per second. There is relatively little danger of overflow of the dam because the greater part of the water which comes to the reservoir is thus under control. Nevertheless, ample provision for wasteways has been made but on a scale by no means comparable to those for the Lahontan Dam.

UMATILLA. A somewhat difficult problem in water conservation has been solved in the case of the Umatilla River in northern Oregon. This stream, flowing in a general northern direction into Columbia River, has early spring floods which quickly run to waste. At the time they occur there is little need of the water. There are few, if any, suitable reservoir sites along the course of the stream, but careful topographic surveys revealed the presence of several depressions or shallow valleys in the relatively flat land near the lower end of the river. None of these localities was particularly attractive and their topographic advantages were lessened by the fact that the country is composed largely of eruptive rocks overlaid with sands and gravels so that there were considerable doubts as to whether the depressions if filled would hold water. The outlets also of these shallow valleys are so broad as to require dams of considerable length to close them. Selection was made of one of these sites known as the Cold Springs and an earth dam constructed, forming a basin of a capacity of 50,000 acre-feet. The maximum height of the earth fill is 98 feet and the length of the crest 3,800 feet. The dam contains 789,500 cubic yards of earth. In outline it is curved in order to fit the contour of the ground. A general view of the upper side of the dam and of the outlet tower is given in Pl. XI. D.

The reservoir is filled by flood water taken from Umatilla

River and conveyed for 25 miles through a canal with capacity of 350 cubic feet per second. The water of the floods in excess of this quantity is necessarily wasted, but by utilizing the canal to its full capacity, there is usually obtained ample water to fill the reservoir during the flood season.

One of the matters which has given considerable concern has been the leakage under or around the embankment. A study of the character of the water issuing indicates that it does not come through the dam but probably percolates in a round-about way through the natural formation. The fact that it issues clear and is decreasing in amount is an assurance of safety. The experience gained in this and similar earth structures leads to the belief that other works of this character can be built to advantage.

The feed canal is shown in Pl. XII. A. At this place it is lined with cement in order to prevent loss of water through the rock, which as shown in the picture is shattered and pervious. Here also there is particular need of care not only for economy of water but to prevent softening the earth of the roadbed of the railroad which lies parallel to and immediately below the level of the canal.

The flood waters delivered into the reservoir are drawn out during the summer season for irrigating about 25,000 acres of land. Much of this agricultural soil is very sandy so that during the first few years the amount of water applied has been excessive. A quantity to a depth of 15 or even 20 feet has been put upon some of the small farms with resulting heavy seepage and necessity for building large drains. With greater skill in applying water, the average duty has dropped to 6 acre-feet, with prospects of still further reduction toward the average of other projects, namely, between 2 and 3 acre-feet.

Minidoka. This combined storage and diversion dam is notable as one of the large structures built of loose rock across the river without diverting the main stream. Provision was made for suitable river gates at the north side and then the main channel was obstructed by large rocks dumped in place and rearranged by the rapidly rushing water. Smaller and smaller stones were dropped on these until the interstices be-

tween the larger blocks were filled and the river raised to a point where it could be diverted through the gates already provided. In the comparatively still water above the obstructions, gravel and finer materials were dropped, making the loose rock structure fairly water-tight. The dam thus built raised the water level about 40 feet and forced the stream into the gravity canals, one on the north and the other on the south side of the river, at the same time making a reservoir, named Lake Walcott, in recognition of the work of Hon. Chas. D. Walcott, now secretary of the Smithsonian Institution, in the reclamation of the arid west.

A considerable amount of water belonging to lower appropriators must be permitted to flow through the dam. As an easily available head of water was thus created by the dam, it was considered wise to utilize this and thus conserve and put to use as far as possible the power resulting. In Pl. XVIII. D are shown the gates installed on the south side of the river channel which, now closed, hold back the flow and force the water to pass through the circular openings above the gates. These openings lead to the penstocks of the power plant which has been erected below the dam. The five large river gates 8 feet wide by 12 feet high are kept permanently closed, furnishing a head of 48 feet used to drive a 7,000 kilowatt power plant. The cost of power produced under these conditions averages slightly over one mill per kilowatt, including all operating expenses and plant depreciation. This low cost makes it possible to sell the energy for many varied and novel uses in the small towns in the agricultural communities which have grown up as a consequence of the building of the irrigation works. A considerable proportion is used for heating. For example, in the new high school at Rupert, Ida., electricity is used for heating, lighting and operating all the devices necessary in a modern high school that includes physical and chemical laboratories. It is this utilization of what may be termed the by-products of water conservation which best illustrates the far-reaching importance of the subject.

To more completely utilize the dam, an extended overflow weir has been built as shown in Pl. XII. B, affording a broad

spillway for the floods which enter Lake Walcott. It follows a somewhat irregular line of lava or basalt. The weir consists of a low concrete wall, on which have been built concrete piers so arranged that by use of flashboards or stop plank the water level can be raised, creating the storage in Lake Walcott of 150,000 acre-feet, of which, however, only about one-third is available above the fixed crest. In the distance is shown the power house above described, this being located near the deep part of the channel immediately below the river gates shown in Pl. XVIII. D.

Bear Lake. An interesting example of water conservation by storage in which the reservoir is created not by raising the height of the water, but by lowering it, is the case of the Bear Lake in northeastern Utah. Bear River, flowing from the mountains of Utah in a northerly direction through a corner of Wyoming, passes by the northern end of the lake and in high water overflows into the broad depression occupied by the lake, the stream receiving back some of the water later in the summer. In its lower course the river is used for developing hydroelectric power, as well as for irrigation. For many years studies have been made of the situation in the attempt to improve the storage capacity. Plans have finally been adopted by a water power company for drawing down the lake, not by dredging out the outlet through the long, flat country which rises to the north, but by lifting the water a few feet out of the lake basin and sending it down Bear River in large quantities at the time of year when needed. Power for pumping is produced by the use of the same water at points farther down the stream, the fall in the river used in developing the power being a hundred-fold that of the lift required to take the water out of the lake.

St. Mary-Milk River Systems. The storage of St. Mary River water in Montana and its transportation across the divide into Milk River is an interesting solution of a somewhat difficult international problem of conservation. The St. Mary receives water from the high mountains of northern Montana, which have recently been included in the Glacial National Park. In broadly viewing the topography of the country it would

appear that the torrents issuing from the eastern slope of these mountains should continue in an easterly direction and be available for use in watering the dry lands lying beyond the foothills. These streams, however, instead of continuing in this general direction are caught by St. Mary River, which turns abruptly northward and flows along the front of the range. The reason for this peculiar behavior lies in the fact that glacial material brought from Canada forms a low ridge sufficient to obstruct the normal easterly flow of the streams and to turn them from the Missouri River drainage into the streams which flow into Hudson Bay. The rain which falls on this low intercepting ridge finds its way eastward by several streams, the principal one known as Milk River. Not heading in the mountains, these are of small size, being dependent upon the somewhat scanty and erratic rainfall. They do not have the continuity of flow which marks the rivers issuing from the snowbanks around the higher summits.

The boundary line between Canada and the United States has been drawn in such a way as to put most of the headwater and sources of water supply for St. Mary River and for Milk River in the United States, each flowing into Canada. Milk River, however, turns toward the east, follows along nearly parallel to the international boundary on the Canadian side, then crosses back into Montana and finally enters the Missouri River in that state. Along its lower course are extensive areas of dry land which need irrigation but for which an adequate supply cannot be obtained from Milk River.

Seeing the large flow of water which is steadily pouring northward into the Hudson Bay drainage, the idea immediately occurs to an observer that this water originating in the mountains of the United States should be held there and utilized if possible for the development of the low-lying dry land in the Milk River Valley of Montana. There are ample reservoir facilities in the natural lakes and broad valleys, but the question at once arises as to whether the water thus stored can be conducted across the low dividing ridge. Surveys of this have shown that although the conditions are more favorable for

diversion at points in Canada north of the boundary, yet it is possible to take the water across the divide within the boundary of the United States and to drop it into the headwater of Milk River. Next, however, the promoter of such an enterprise is confronted by the fact that the waters continuing on their way to the lower Milk River Valley in Montana must flow into Canada. Traversing a part of the country they return naturally to the United States. It was found to be practicable for the Canadians to divert this water while it was on its way down the channel of Milk River and to take it out on to the lands lying north of the valley so that even if water was stored in the United States, taken across the natural barrier and started on its way to the lower Milk River Valley in Montana, it might be diverted from its course in Canada.

Each country naturally desires to obtain as much of the available water as possible. The Canadians have built large irrigation works heading on St. Mary River immediately north of the international boundary; also other works, a part of the same general system, which can take water from Milk River. In the United States many canals were built further down on Milk River and lands under these developed to an extent where there was urgent need of water during the crop season. After many negotiations, a treaty, dated January 11, 1909, was finally concluded between the United States and Great Britain, in Article VI of which it is stated "that the high contracting parties agree that the St. Mary and Milk Rivers and their tributaries in the State of Montana and the Provinces of Alberta and Saskatchewan are to be treated as one stream for the purpose of irrigation and power and the water thereof shall be apportioned equally between the two countries."

With this understanding the United States proceeded to utilize its share of the water and to complete a conduit with a capacity of 850 cubic feet per second for taking water from St. Mary River to the headwater of Milk River down the channel of which the stored supply might travel through a portion of Canada and back into the United States to the irrigation system built by the Reclamation Service in the Milk River Valley.

In this instance the natural difficulties to be overcome in the

way of storage and diversion of water are not as serious as those interposed by artificial conditions such as the laws of the two countries and the conflicting claims which arise because of the fact that there is not enough water to meet the desires of both sets of claimants. The structures are notable perhaps mainly from the fact that they are built in a northern region where the climatic conditions are extreme and where ice may be expected to interfere with the manipulation of the works at critical times. The storage dams already completed are similar to those built elsewhere, the principal feature being the canal about 30 miles long which, starting from the west side of the St. Mary River, follows down the valley and then, before reaching the international boundary, turns abruptly, the water being continued across St. Mary River in steel pipes.

After entering the Milk River Valley, the water follows natural channels into Canada, then along the north side of the boundary, and enters the United States. It is finally diverted into the low-lying reservoirs in the vicinity of the agricultural lands. The successful operation of these works brings in many complications because of the long distance from the reservoir on the headwater to those in eastern Montana. There will also be for many years a necessity of exercising almost daily discretion in the adjustment of conflicting claims to the water between the citizens of the two countries.

Deliveries to Reservoir. In planning works for water conservation the practicability of one scheme or another often rests on the possibility of bringing water to a dry but otherwise desirable reservoir site. In several of the storage works just described the necessity was shown of procuring water at some considerable distance, taking it through flood water canals built for this purpose and utilized only during the time of an excess of water in the river. Such a canal has been noted in connection with the Umatilla Project, see Pl. XII. A. An earlier and larger feed canal used also to some extent for direct irrigation is that shown in Pl. XII. C. This is the cement-lined conduit described on page 162, which takes the water of Truckee River out of the stream near the lower end before being lost in its sinks and carries it on a gently descending

grade along the mountain side for thirty-one miles. The canal has a capacity of 1,500 cubic feet per second. For the most part it is necessarily narrow and deep, and occasionally passes through short tunnels.

When the cement-lined canal from Truckee River leaves the narrow valley and reaches the open country, it widens. Some of the water is there used for irrigation and the remainder is discharged into the reservoir on Carson River above the dam described on page 163. The illustration, Pl. XII. D, shows this reservoir site not yet filled, with the Carson River in the distance and in the foreground the water from the Truckee Canal. At this point the descent to the reservoir is rapid. At the lower end a concrete chute is provided, inclined upward at the tip in order to throw the water clear of the foundation. The picture illustrates an interesting phenomenon in the flow of water. It is rushing down at high velocity and at this stage accumulates in a large standing wave as shown in the foreground of the picture. When the volume increases somewhat, however, this wave is swept out and with increased flow at this point, the stream continues unbroken to the very end of the chute.

Underground Storage. Nature has made provision for water storage not only in the lakes and ponds which dot the map, but in less evident ways. In many localities water is stored underground, as noted on page 76, not in spacious caverns as popularly supposed, but in innumerable tiny interstices between the gravel pebbles or particles of sand. Such material has accumulated on the lowlands along the rivers, usually as a result of storms washing down the disintegrating covering of the hills. It is evident that at the time of deposition of this sand and gravel by rapidly flowing water, the mass was saturated and thus remains until the water is slowly drawn off.

In the arid valleys of the west the gravels have accumulated to an extraordinary depth because of the fact that many of the streams from the steep mountains are intermittent and torrential in character. They bring down during annually recurring storms more material than can be transported across the more nearly level plains near the foot of the hills. Some of these mountain valleys because of later earth movements are

now completely inclosed; the rivers no longer escape to the sea, but disappear in marshes or alkaline lakes. The gravel terraces and valley slopes even where dry on the surface have received and retained much of the water which has come from the hills. When this water is not too heavily charged with earthy salts or alkali, it has great value for use in the drought-stricken areas. This condition is particularly notable at the outlets of the narrow canyons where the bowlders and smaller stones have been deposited in the form of low cones or deltas over which after storms the water flows, a part of it disappearing into the gravel masses and then slowly seeping to lowlands. The water thus temporarily or permanently stored in these gravel cones can frequently be recovered by tunnels or deep trenches and thus utilized during the crop season. In the springtime the gravel cones are again replenished from the floods and thus there is provided, as above noted, a reservoir which is highly effective in time of need.

Investigations of the extent and availability of these natural storage reservoirs have been made by the United States Geological Survey and various publications prepared, notably in relation to irrigation development.[1] The importance of these waters stored underground is attested by the vigorously contested lawsuits concerning their ownership and control—in particular the case between San Bernardino County in California on one side and Riverside County on the other relative to the artesian waters of San Bernardino Valley. This case has required a more exhaustive study of details than, so far as known, has been undertaken in similar work. The examinations extend into the geology, hydrography, and conservancy features, accompanied by the spreading of flood waters over the

[1] See J. B. Lippincott, U. S. G. S., Water Supply Papers Nos. 59 and 60, relating largely to the underground water supply of San Bernardino Valley; Mendenhall in Paper No. 142, giving details particularly of the geology, and Charles Lee on the water supply of the Owens Valley in Paper No. 292. Also Frank H. Olmstead on "Control of Mountain Torrents by Check Dams" in *Engineering News*, February 17, 1916, p. 314; H. F. Olmstead in *Engineering Record*, May 13 and 20, and by O. E. Meinzer and A. J. Ellis on "Ground Water in Paradise Valley, Arizona," and by O. E. Meinzer on "Ground Water in Big Smoky Valley, Nevada."

gravel beds at the edge of the valley. Extensive tests have been made on the effect of opening and closing artesian wells.

The water which is stored underground can be utilized sometimes by direct gravity flow as, for example, where the saturated deposits of sand and gravel lie on the hill slopes in such position that a tunnel can be driven on slightly ascending grade to penetrate them and draw out the waters which are slowly percolating downwards. At various times considerable popular interest has been taken in these so-called underflow tunnels, particularly out from the Great Plains. (See page 78.) It was known that there were considerable bodies of water underground saturating the sands and gravel and that this water had a general movement toward the east and south. The rate of movement, however, was exaggerated, as it was not appreciated that this is extremely slow, being perhaps at the rate of a foot or two a day. (See page 79.) The level of the country drops towards the east at the rate of about seven feet to the mile. If an open trench or tunnel starting at the ground level were continued westerly with a rise of 0.5 foot per mile, at the end of the first mile it would be 6.5 feet beneath the surface and in ten miles 65 feet deep. It was assumed that this tunnel would tap the so-called underflow and permit it to flow easterly to the surface of the ground.

Large amounts of money were spent in building works of this kind, but after the near-by deposits were drained of water, the progress of percolation was found to be so slow that a very small stream of, say, a second-foot or less was obtained. In other words, the cost of the tunnel was disproportionately large when compared to the value of the supply. An equal amount of water could have been pumped at far less cost.

Pumping to bring this stored water to the surface (see page 221) and to furnish an adequate supply for agriculture and other purposes is being resorted to in a continually increasing degree. An almost innumerable variety of mechanical appliances are being improved and developments are taking place along various lines, particularly in the use of electrical power and in the perfection of the steam and gas engines. The oldest and simplest devices and one of the most widely used are various

forms of windmill or wind engines. From the earliest times the power of the wind has been employed to supplement the strength of man and of animals in lifting water for irrigation and drainage. The great mills built by the Dutch for reclaiming the lowlands of Holland are particularly well known. Modern developments have resulted in building comparatively cheap, rapid-running steel mills. These are used by the thousands, particularly in countries, as in Kansas and Nebraska, where there is considerable wind movement throughout the year. There they are employed largely for pumping water for domestic supply and for watering animals. To a less extent they are utilized in bringing water which is stored underground to small reservoirs or tanks on the surface, as shown in Pl. IV. A, where it can be held and usually warmed by the sun until needed for irrigation of gardens.

Where wind movement cannot be depended upon, steam power is being largely employed. This finds a competitor in the gasoline engine, especially in power plants. One of these small irrigation systems is shown in Pl. XIII. A, where there is an earth tank or pond built above the general level of the adjacent country. Water is pumped into this from the so-called underflow and is drawn out as needed for the irrigation of the sugar beets in the vicinity. (See also page 221.)

Plate XI. A.
Dam at head of Sunnyside Canal, Washington, diverting water which comes from storage at the head of Yakima River.

Plate XI. B.
Lower embankment of Deer Flat Reservoir, Boise Project, Idaho.

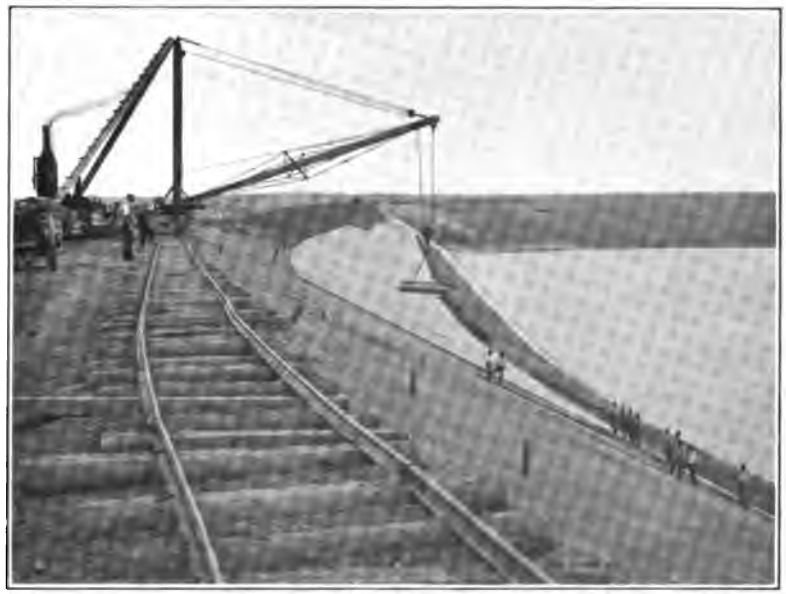


Plate XI. C.
Laying concrete blocks on upper face of Owl Creek Dam, Belle Fourche Project, South Dakota.

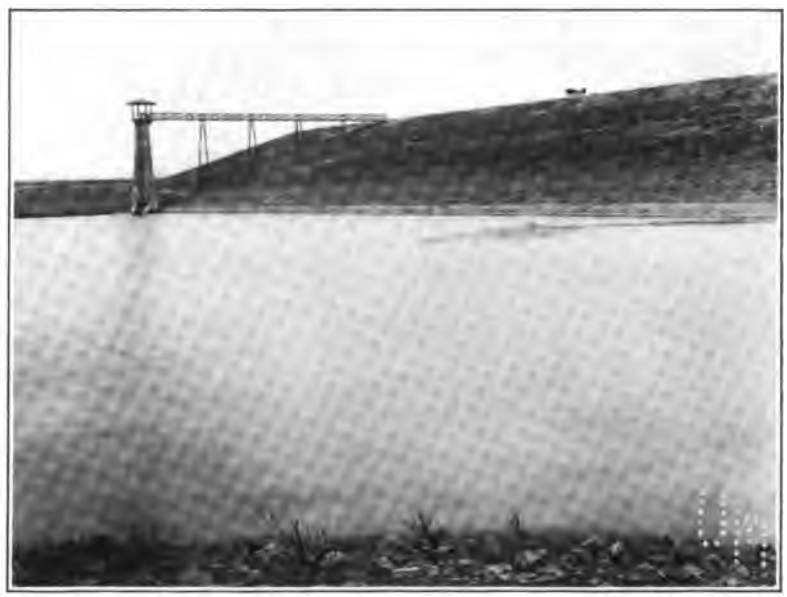


Plate XI. D.
Cold Springs Dam and outlet tower, Umatilla Project, Oregon.

CHAPTER X

USES OF WATER

COSTS AND BENEFITS. The feasibility of water conservation by storage is dependent largely upon questions of economics, that is, of relative cost and benefits, and these in turn rest upon the uses to which water may be put. Although it might not be profitable to conserve water for irrigation alone, it may pay to store it for municipal supply combined with irrigation and power development.

Thus in any discussion of water conservation it is necessary to consider the ultimate uses of the water as these bear directly upon the practicability of incurring considerable expenses for any proposed system.

There is a wide divergence in the uses, some being of such character that any expenditure would be proper, as, for example, in procuring pure water for drinking; to save and prolong life, a man or community will be justified in going to any length. On the other hand, there are uses which cannot be considered unless water is abundant and cheap. For example, in some manufacturing processes the margin of profit is so small that the question as to whether the enterprise is worth undertaking is determined by the fact as to whether there already exists plenty of good water which can be had at a merely nominal cost.

In considering the uses of water and consequently the expenditures which may be made in conservation by storage, we may divide these uses into five classes.[1]

First, support of life.

Second, production of food.

[1] See Progress Report of the Special Committee on "A National Water Law," Proceedings of the Am. Soc. C. E., December, 1915, p. 2747.

Third, carrying away wastes.

Fourth, manufacturing, including water power.

Fifth, navigation.

This relative rank has not been widely adopted in the past; on the contrary, from a legal standpoint, the claims of navigation are often given precedence over other uses. This is because of the fact that in the early days there was usually plenty of water for all ordinary purposes. Manufacturing had not developed any considerable needs, while on the other hand, the transportation of persons and goods by water was imperative.

In the treaty with Great Britain signed January 11, 1909, and promulgated May 13, 1910, relating to boundary waters, it is stated in Article VIII that "The following order of precedence shall be observed among the various uses enumerated hereinafter for these waters, and no use shall be permitted which tends materially to conflict with or restrain any other use which is given preference over it in this order of precedence:

(1) Uses for domestic and sanitary purposes;

(2) Uses for navigation, including surveys of canals for the purpose of navigation;

(3) Uses for power and irrigation purposes."

From the standpoint of human needs it is probable that irrigation, which means the production of food, should have precedence over everything except domestic and municipal supply, and that the development of water power is more important to humanity than navigation as now employed. However this may be, there is no question but that all uses must yield to those of prolonging life.

Support of Life the First Use of Water. The first and most important use of water to mankind is for drinking purposes; this is self-evident since it is not possible for a human being to exist for more than two or three days without water. More than this, continued health is dependent upon having an ample supply of water of a high degree of purity, especially one not polluted with animal or vegetable matter. It is possible to continue to drink water containing a considerable amount of mineral matter but on the whole the more nearly pure the water the better the general health of a community. Absolutely pure

water cannot be had, and the nearest approach to this is rain water, especially that caught after the first part of the shower has washed out most of the dust in the air.

Because of the prime importance of water for drinking and for domestic and municipal supply, it is practicable and desirable to make large expenditures for water conservation by storage for such purposes. In fact the needs of mankind are such that no expense is too great to procure good water, assuming that such expenditure is advisedly made. For this reason some of the largest engineering works in the world have been built for municipal supply. Such work includes dams creating reservoirs, especially in the mountains where the purest water can be had, also long aqueducts constructed to bring this water to centers of population.

The amount which can thus be expended in procuring good drinking water is limited only by the resources of the people. Practically, however, other considerations have come into play and, unconsciously at least, there has been a weighing of costs and benefits in which human life and comfort have not always been valued at their true worth. In other words, while theoretically a community should utilize all its resources to procure good water, practically the consideration of cost is balanced against the prevailing opinion of the value of human life and the risk which may be assumed. This is not done in a direct manner but, until the loss of life and health becomes alarming, the ordinary community does not bestir itself to make strenuous effort to procure good drinking water. Or to put it in another way, the men in responsible charge usually have the feeling that the penalty of neglect will fall on some other person: although they would indignantly deny the charge, yet a careful analysis will reveal the conviction that only the poorer or less worthy members of society will suffer.

A rather interesting example of justice in this regard has been furnished by a recent event in one of the smaller cities in Illinois. Here public sentiment was strongly aroused because of the known pollution of the city supply and the necessity of taking immediate action. The mayor, however, a man of strong personality, stood out against the proposed changes, urged

that the community had always used the water from that source and, on the ground of economy, was successful in defeating the effort of the great body of citizens. He himself was one of the first victims of the typhoid epidemic which followed: he paid with his life for his attempt to cut down necessary expenditures. If each instance of parsimony or of official indifference were followed by such prompt penalty the loss of life and health due to the neglect of water conservation and protection would cease.[1]

Quantity Needed. The amount of water actually needed for supporting life is relatively small. It is necessary for an ordinary individual to have approximately four pounds daily and under normal conditions, comfort is assured only by having this amount available for use at short intervals. Some animals drink very little water, but obtain the needed liquid through the herbage cropped. In the case of the camel it is stated that he has traveled 500 miles in 40 days with only 3 gallons of water on the thirty-second day and 3½ on the fortieth.[2]

Although a very small quantity, namely, a half gallon per person each day, is absolutely necessary, yet in constructing waterwork systems, it has been found that to bring this half gallon to the individual needing it and to supply his other needs connected with cooking, washing and other household purposes, from 100 to 200 times this quantity is demanded. In European cities 40 to 50 gallons per day per inhabitant are not unusual. In the United States the quantity usually taken as a fair minimum is 100 gallons per day per unit of population. It is thus apparent that in considering water conservation for supporting life, a large allowance must be made for related purposes.

In this connection it may be well to call attention to the value put upon human life as compared with the cost of safeguarding it. One of the best discussions on this point is that given by Marshall O. Leighton in *Popular Science Monthly*, June, 1902, Vol. 61, p. 120, where he arrives at an estimate for various ages

[1] Bass, F. H., "The Public Water Supply and Means of Protecting It," 1910.

Hazen, Allen, "Clean Water and How to Get It," John Wiley & Sons, 1914, 196 pages.

[2] Coles-Finch, "Water, Its Origin and Use," p. 430.

based on court decisions, in which award was made largely on life expectancy but without consideration of the suffering embodied nor any punitive measure nor solace to the survivors. In some cases the state law sets a maximum of $5,000, but by taking an average of all the cases the values range from approximately $1,000 at 5 years of age up to $3,000 at 16 years, then increasing rapidly to about $7,000 at 30 years, dropping sharply to old age.

It is apparent from the action which has been taken by courts and by administrative bodies that there is a certain pecuniary value kept in mind and that this is subject to the same economic laws as ordinary commodities. Unconsciously, at least, some such values enter into so-called practical consideration as to whether or not a community will incur large expenses for obtaining good water and thus reducing the death rate. Purely humanitarian considerations must be supplemented by the logic of the saving in money to bring conviction to certain types of mind.

Value of Pure Water. The value of pure water is to a certain extent fixed by the value set upon human life, as above noted, and upon comfort, as well as upon industrial conditions. This has been discussed by George C. Whipple in his "Value of Pure Water," 1907. Without pure water any community is subject to lower health conditions, and with water occasionally polluted there is constant danger of typhoid and similar diseases. In fact, the typhoid death rate to a certain extent marks the degree of purity of water supply. Under ordinary conditions no town can grow or increase in prosperity which does not guard its reputation in this way.

In speaking of pure water from a sanitary standpoint there is not implied the degree of purity required by the chemist. In fact a good or fairly wholesome water may contain a considerable amount of coloring matter or of various earth salts or mineral matter in solution; also considerable organic matter, although the presence of the latter should give rise to suspicion. To be safe as well as palatable a water should be reasonably clear, odorless and tasteless and free from contamination by sewage or industrial wastes.

Various waters which are highly charged with mineral matter may be used for drinking and some are regarded as having desirable medicinal properties. These have been classified into thermal or warm waters, muriated or containing traces of chlorine, alkaline such as most western waters containing sulphates and carbonates, sulphated having sulphates in excess, chalybeate or iron bearing, sulphur, calcareous, etc. That these mineral waters are considered as having value is shown by the fact that quantities valued at about $7,000,000 are disposed of annually, of this over $1,000,000 being imported from abroad.

At the present time the greatest activity in water conservation as well as in hydraulic engineering in general is in connection with procuring water, suitable in quality as well as quantity, for domestic supply, especially for municipalities. The ideal condition for obtaining water for drinking and related purposes is from some elevated watershed which can be protected from intrusion and where the erosion of the soil may be prevented by the maintenance of forests or other suitable vegetation. Such conditions are found, for example, in the water supply of Portland, Ore., which obtains its water from a national forest, a vast tract of almost unexplored wilderness.

Favorable surroundings such as these are rare and for large cities such as New York and Boston it has been necessary to purchase large areas of land near the headwater of small streams and to build storage reservoirs; in some instances small towns and factories have been removed in order to secure the necessary land and to insure the purity of the supply. Among the more notable works are those of the city of Los Angeles, Cal., which brings its water supply from Owens Valley, a distance of upwards of 240 miles.

The use of water taken directly from a reservoir or stream is gradually being abandoned in favor of some form of filtration. Theoretically the water stored in a reservoir should be so protected from pollution as to be suitable for use, but frequently it happens that the waters are not only contaminated but in the reservoir itself organic matter develops and certain changes take place causing the water to deteriorate and to become unpalatable because of color, taste, or odor. For this reason, and

also because the density of population increases the corresponding danger of pollution, more and more complete systems of filtration are being introduced.

CHAPTER XI

FOOD PRODUCTION THE SECOND USE OF WATER

After air, without which man can live only about two minutes, and water, without which man can exist for about two days, comes food. This he should have daily and must have at short intervals to maintain strength. Men have lived 30 or 40 days or even more without nutrition, but with rapid running down of activities. All food materials, whether for plants or animals, require water. Plants receive their supply mainly through the moist earth, which in ordinary soils should contain from 8 to 16 per cent of water in order that the plants may thrive. If in certain soils the percentage drops much lower the plants wilt, and if it rises much higher many of them become drowned out. There is thus a narrow margin which must be preserved to enable plants to find nutriment for themselves and to act as food for animals. This proper proportion of water, if not the result of natural conditions, may be produced artificially either by irrigation, by bringing water to the plants when needed when the water content of the soil drops below a certain point, or, on the other extreme, by drainage to remove the excess.

The watering of livestock is a use which may be considered in this connection and which usually takes precedence even over that of irrigation of the ground. Thus in this second class of uses of water, that in food production, there come the following items.

(a) Watering livestock and maintenance of animal industry.
(b) The production of crops by irrigation.
(c) Increase of crops by drainage.

In watering livestock, conservation by storage is widely em-

Plate XII. A.

Main feed canal, concrete-lined section, for carrying flood water to Cold Springs Reservoir, Umatilla Project, Oregon.

Plate XII. B.

Spillway of the Minidoka Dam, Idaho, with power house in distance.

Plate XII. C.
Cement-lined canal carrying the water of Truckee River to Carson Reservoir, Nevada.

Plate XII. D.
Flume delivering water of Truckee River into Carson Reservoir, Nevada.

ployed, especially in great pastures and on the plains where the cattle roam at large. Throughout the western part of the United States, thousands of small reservoirs have been built for this purpose. Some of these are formed by damming the little streams and others are depressions in the ground into which water is pumped usually by windmills. From the earliest antiquity there was resort to this kind of water conservation. In the biblical narratives there are accounts of deep wells or springs developed and protected for the purpose of watering the cattle and sheep.

Irrigation and Drainage. Throughout the western two-fifths of the United States on much of the best agricultural land the rainfall is insufficient in quantity, or so irregularly distributed throughout the year that valuable crops cannot be produced with certainty without an artificial supply of water provided largely by storage. In the Mississippi Valley and to a certain extent in most of the states of the Union there are vast tracts of otherwise fertile lands which have an excess of water to a degree such that crops cannot be profitably raised. Here the hydraulic engineer is called upon to solve the problems of drainage. In many respects these are similar to those of irrigation and are intimately connected with it, as the object to be attained is the maintaining of the moisture in the soil within relatively narrow limits.

For the production of crops by irrigation or for relieving the lands of an excess of water by drainage, quantities of water must be handled which are relatively large when compared with those needed for city supply. For example, a 160-acre farm will require for its irrigation or may need for drainage the handling of a volume of water as large as would be needed for domestic or general supplies if the area were covered with dwelling houses or factories. When it is considered that an ordinary American city of, say, 100,000 persons covers an area of about 10,000 acres, while an irrigation or drainage project may include 100,000 acres or more, some conception may be had of the relative magnitude of the works needed for the two purposes. Although for irrigation or drainage there must be constructed works of large capacity, yet it is not practicable

to pay for these works an amount comparable with the expenditures which may properly be incurred by a municipality.

For farming purposes a cost of irrigation exceeding, say, $100 per acre, or for drainage, $50 per acre, may be practically prohibitive, but for municipal supply the cost of providing water for a similar-sized, but densely populated area may properly run into thousands of dollars. Thus the hydraulic engineer, while encountering in either instance problems of quantity and quality of water, adequacy of supply and difficulties of storage and distribution, must keep down the cost of these works to a small fraction of that which is feasible in considering questions of municipal supply.

In preparing for irrigation or drainage extensive studies must be made by the engineer and detailed maps prepared to show the topography of the country from which water may be obtained for irrigation and to which it may be carried. This mapping should be accompanied by measurements not only of the rainfall, wind movement, and other meteorological phenomena, but especially of the flow of various streams at typical points on their course. Problems of flood conservation or water storage are usually involved, these being on a larger scale than those in connection with municipal supply. The result of these measurements of rainfall and run-off should be available for a considerable period of time as the fluctuations during five consecutive years, particularly in the arid region, may not fully reveal the ordinary conditions. Ten years are better, but it appears from study of data now available that the engineer cannot assume to have complete knowledge of the climatic fluctuations from observations extending for a shorter period than half a century. Of course, it is impossible to wait that length of time before preparing plans for works, but when utilizing data which extend over a short period, a large factor of safety, especially with reference to extreme drought and flood, should be employed. (See page 57.)

The United States government has recognized the necessity of being prepared to furnish data of this kind and has instituted through its Weather Bureau and Geological Survey a series of observations of climatic factors and stream flow, which

enables the hydraulic engineer to make his estimates with a fair degree of accuracy.

Rapid advances have been made throughout the United States, especially the western or arid portions, since 1900, in the construction of larger storage reservoirs and of distributing canals for bringing water to agricultural lands; so that in 1918, about 16,000,000 acres were under irrigation, out of possibly 50,000,000 acres in all, which may be watered. Also in other parts of the country drainage works have been provided for, say, 10,000,000 acres out of 70,000,000 acres needing such treatment to relieve the lowlands of an excess of moisture. No accurate statistics are available of these acreages. Large works have been and are being built, notably in Egypt, India, South Africa, and Australia, by the British engineers. In other dry lands, notably in Spain and Italy, there has been a gradual development and in many cases restoration and enlargement of great works built centuries ago.

While the necessities are not such as to justify as large expense per unit of water stored, in the case of irrigation as in municipal supply, yet the values involved are sufficiently great to warrant large outlay for irrigation works. For example, comparing the land in its original condition as shown in Pl. XIII. C, with the companion view, Pl. XIII. D, it is apparent at once that this desolate area, with an occasional patch of prickly pear, has little, if any, value. It may sell at the government price of $1.25 per acre and be used as a stock range when there may be some herbage following the infrequent rains. But compare with this the same area after water has been brought to it from a storage reservoir located in the mountains. Here the settler is able almost the first year to secure a fair crop and the land provided with water will pay an interest charge on, say, $100 per acre. If we assume an average cost of irrigation at $50 per acre and that a tract of 100,000 acres can thus be supplied, it is assumed that an outlay of $5,000,000 would be justified. For this sum works of considerable magnitude can be built. In this view, Pl. XIII. D, the area has been planted in alfalfa, the most important crop of an irrigated region. This is not only cut as hay, crop following crop,

throughout the season, but is especially valuable in its green state in the production of pork and in the feeding of farm animals.

INTERNAL EXPANSION. It is by means of this kind that it becomes possible to greatly extend the area of land available for agriculture and related purposes, and thus to realize the dreams of increase of available territory without encroaching upon neighbors. The engineer by conservation of water is thus creating new and valuable agricultural lands and making opportunities for self-supporting citizens in localities where up to this time there has been merely waste space. He is adding not merely to the material prosperity of the country, but more than this, he is increasing the opportunities for better citizenship, for greater health and comfort and for the enjoyment of many of the higher ideals of life. He is bringing about an internal expansion of usable territory far more valuable than the mere extension of external boundaries.

This internal expansion is, in effect, the putting into practice of the principles of conservation; a term which really implies good business management, or common sense applied to the use of natural resources. The engineer, finding that certain areas are neglected or that agriculture is not being practiced to its highest efficiency, knowing also that the soil is fairly good and that the climate is adapted to the production of crops, naturally inquiries into the reasons. He tries to ascertain the cause for the lack of full use of the lands. This he discovers is usually connected with an excess or deficiency of water supply. He finds that the plants useful for mankind are adapted to a relatively wide range of soil and temperature, but are more narrowly limited by the quantity of moisture. More than this, he appreciates that the control of the water, while in part an agricultural operation, is largely dependent upon the application of engineering principles.

Knowing, for example, that a certain area is arid and desert, or subject to periodical drought, the first consideration of the engineer is to seek out the sources from which water may be obtained and brought to the land to raise the water content

of the soil from the original 1 or 2 per cent up to 10 per cent or more.

On the other hand, finding a neglected or abandoned swamp or overflowed area or one whose soil is habitually wet or heavy, the problem presented to the engineer is to take away this excess and bring the water content down from the saturated condition of 100 per cent to 15 per cent or less of water.

These two operations are intimately connected because of the fact that when water has been provided in abundance for a piece of arid land the tendency is to use the water in excess and to saturate it to an extent such that a large part of the area is injured for agricultural purposes. It thus becomes necessary to provide means for reclaiming these saturated lands; drainage is found necessary in localities where in their original state the lands were dry and barren.

Irrigation and drainage are thus related, much in the same way that city water supply and sewage are connected. The better the water supply, the more complete should be the sewage system. The larger the supply of water for irrigation, the more necessary the installation of effective drains and waste-ways. This very simple relation has very frequently been overlooked or at least ignored to an extent such that throughout arid North America, 15 per cent to 20 per cent of the irrigated lands, formerly producing large crops under irrigation, have been ruined by careless handling of the water and by lack of drains. The surface has been converted into swamps or covered with alkali over tens of thousands of acres.

The watering of lands by artificial means to increase crop production, is widely practiced in the western or arid portions of the United States, as well as in the dryer parts of the Old World. It necessitates the application of many of the principles of hydraulic engineering and in addition, as above noted, requires for success a knowledge of agriculture and related economic matters. There is, on the whole, a far larger extent of dry land than can ever be provided with sufficient water for maturing crops. Thus land values, in a large way, depend upon the ability to obtain water; many other industries besides agri-

culture can be developed only in localities where an artificial water supply can be had.

Irrigation in the United States began with a few hundred thousand acres in 1880, by 1890 the irrigated area had increased to approximately 4,000,000 acres, in 1900 to 8,000,000 acres, and in 1910 to 14,000,000, representing a total investment of approximately over $300,000,000. The hydraulic works for conserving and distributing the scanty water supply have been built to a point where all of the easily available sources of water have been utilized. Future progress must necessarily be relatively slow and expensive because of dependence upon works of increasing magnitude and cost per acre served. This cost, beginning originally with $15 or $20 per acre from small canals built by farmers, has increased to an average of about $50 per acre for supplies obtained from the larger and more difficult undertakings such as the Roosevelt Reservoir in Arizona and the Arrowrock Dam in Idaho. The most notable advances in irrigation development were made possible by the passage of the Reclamation or Newlands Act, described on page 149.

Nearly 95 per cent of the lands irrigated in the United States obtain their water supply by gravity from surface streams. A relatively small, but valuable area, is watered from wells by means of pumps driven by steam, gasoline or hydro-electric power. Most of the streams of the arid region have their source in the snow-capped or forested mountains, from which they flow with rapid descent, passing usually through a series of upland valleys or parks and then cut their way through rocky defiles entering upon the lower valleys. In these the streams spread out and usually lose a great part of their water in broad sandy channels. The most effective development of the stream therefore is that in which the water is diverted near the upper edge of these lower valleys and carried out in channels so built as to conserve the supply which would otherwise be lost in the sandy channels.

Diversion of Water. Water is ordinarily diverted from the stream, not by lifting or pumping from the stream as sometimes inferred, but by taking advantage of the slopes of the country. For example, the streams on issuing from the moun-

tains have a rapid fall of from 10 to 50 feet per mile or more. Water will flow with moderate rapidity in a well-built canal having a fall of 1 foot per mile or even less. Assuming, then, that the stream enters the valley on a descending grade of 10 feet per mile and the canal is started out alongside the stream with a fall of 1 foot per mile, at the end of 10 miles the canal will be 90 feet above the river and must necessarily have swung back away from the river to be upon supporting ground. Thus it results that the canal departs rapidly from the river and, following the contour of the slopes of the foothills, is in position to discharge water toward the river over or through the lands which lie below the canal.

In order to facilitate the taking of water from the river into the canal, it is usual to provide a low overflow dam or weir which extends from the head gate of the canal across or diagonally into the channel of the stream. If the topographical conditions are favorable, this weir may be omitted or in case of small irrigation canals, where the owners are unable to provide a permanent dam, it is customary in summer or on the approach of the low water season to build a temporary obstruction of stone and brush, turning the water toward the head gate of the canal. As the water continues to fall, this dam is made more nearly impervious by adding straw, earth or sandbags. It is necessary to provide some form of head gate to control the amount of water which enters the canal. Otherwise in time of flood the excess, getting into the canal, might overtop the banks and wash them away. Head gates are also needed to regulate the quantity in accordance with the needs of the irrigators. These usually consist of stout walls and frame built of timber, masonry or concrete with sliding gates of wood or steel. The water enters under the raised gates, the quantity being controlled by adjusting their position.

The canal leading from the head gate usually passes through a rocky or rough country, involving large expense in construction before the more nearly level open land is reached. In this upper part of the course it is sometimes necessary to carry the water in tunnels through projecting cliffs or to provide suitable timber, metal, or masonry flumes to take it across rough coun-

try. When once the canal is out upon the agricultural land it is usually excavated with broad, shallow sections, keeping the water surface as high as possible, consistent with safety, so that water may be diverted to the adjacent fields on the lower side of the canal. The fall or slope of the canal, taken in connection with the cross section, is so proportioned as to give a velocity in ordinary earth of a little over two feet a second—not enough to erode the sides and bottom nor so stagnant as to deposit silt usually carried by mountain streams. Considerable skill and experience are required on the part of the designing engineer to lay out the canal system and its laterals or distributing branches so as to avoid erosion and sedimentation.

Quantity Used. The amount of water required for raising crops varies according to the character of the soil. The plants themselves need a certain minimum supply, but a far larger quantity is required to saturate the surrounding soil to such a degree that the vitalizing processes can continue. Agricultural investigators have found by direct measurements that from 300 to 500 pounds of water or even more are required for each pound of dry matter produced. When the ground is first irrigated a larger quantity of water than in later seasons is sometimes required to saturate the subsoil. The water turned upon the surface and absorbed during the first year or two has frequently been equivalent to an amount sufficient to cover the ground to a depth of 10 feet or more, and in many localities an amount equal to a depth of 5 feet or more per annum has been thus employed for several years. The pioneers of irrigation usually apply too much water to their fields, often to their disadvantage.

The quantity of water used in irrigation is usually stated in one of two ways: (1) In terms of depth of water on the surface; (2) in quantities of flowing water through the irrigating season. In the humid regions the rainfall is usually from three to four inches per month during the crop season. In the arid region, where the sunlight is more continuous, and the evaporation greater, there should be for ordinary crops at least enough water during the growing season to cover the ground from four to six inches in depth each month or from a third to half

of an acre-foot. The second method of stating the quantities necessary to irrigation is of convenience when considering a stream upon which there is no storage.

It is estimated, as noted on page 105, that one cubic foot per second, flowing through an irrigating season of 90 days, will irrigate 100 acres. One second-foot will cover an acre nearly two feet deep during 24 hours, and in 90 days it will cover 180 acres one foot deep, or 100 acres to a depth of 1.8 feet, or 21.6 inches. This is equivalent to a depth of water of a little over seven inches per month during the season of 90 days or about one and three-quarters acre-feet. Successive years of deficient water supply, notably in southern California, have served to prove that, with careful cultivation, crops, orchards, and vineyards can be maintained by using very small quantities of water. In some cases an amount not exceeding six inches in depth was applied during the year, this being conducted directly to the plants and the ground kept carefully tilled and free from weeds.

The amount of land which can be irrigated with a given quantity of water, or the relation which these bear to each other, is commonly expressed by the term duty of water, as discussed on page 232. The investigation of the duty of water is one of the most complicated problems of irrigation. There is such a difference in methods of measurement, soils, crops, climatic conditions, ways of application of water, and frequency of watering that the statements made by different persons are almost irreconcilable. In general, more water is used, or the duty is less, on the newer land than on that which has been cultivated by irrigation for some years.

The rainfall largely affects the quantity used, and as the precipitation is exceedingly irregular, as noted on page 55, the amount of water applied each year fluctuates. Seepage likewise complicates matters, for a field may often receive considerable water indirectly and require less by direct application. The duty of water is quoted at from 50 to 500 acres or more to the second-foot. For convenience the unit of 100 acres to the second-foot has been considered as indicating careful irrigating, although in the more southwestern portion of the arid

region this would be considered low, and in the northern part high.

Since the value of water per second-foot varies largely with its duty, it will be recognized that this value is exceedingly difficult to estimate. However, it is necessary to arrive at certain averages in order to approximate the possible values of a river, or of a reservoir, in the future development of the country. It has been estimated that a perpetual water-right is worth from $25 to $50 per acre in a grain or grazing country, and as high as from $100 to $500 per acre for fruit-land, rising in southern California for the best citrus lands even to $1,000 or more per acre. Assuming an annual supply of water as being worth $50 per acre irrigated and a duty of 1 second-foot to 100 acres, this quantity would be worth $5,000 and a stream furnishing a steady supply of 500 second-feet would have a value to the community of $2,500,000. Considering stored water as having a value of $100 per acre of reclaimed land, producing fruit or other valuable crops, and with a duty of 2½ acre-feet of stored water to each acre, then a storage reservoir capable of holding and delivering 250,000 acre-feet might justify an expenditure of $10,000,000.

Cost of Water. The first cost of water and the annual cost of maintenance form very considerable items in the budget of the irrigator. As an equivalent for this expenditure he must expect to receive a return per acre for his crops greater than that obtained by the so-called "dry farmer." As a matter of fact, he can raise few, if any, crops without irrigation, but with it he should be able to obtain a yield far in excess of the ordinary production because of his ability to control the water supply and to use it on a land from which the sunshine is not cut off by frequent rain clouds.

The cost of water is usually considered under two heads, *first*, that of the original investment in obtaining water by reservoirs, canals and distributing works and, *second*, the annual cost. The first cost ranges from $10 to $15 per acre, in case of the older and more easily built ditches, up to $50 or $75 per acre or even more where it has been necessary to provide expen-

sive storage reservoir or to overcome natural obstacles by building tunnels or masonry and concrete conduits.

The average first cost of water in the United States is not far from $50 per acre. The commercial enterprises which have undertaken to build irrigation works have usually attempted to control the land reclaimed and to sell land and water together at a price of $100 per acre or more, including some improvements in the nature of removing the native vegetation, leveling the soil and planting alfalfa. Without such control of the land, investments of this kind have rarely been profitable. In case of works built by the government the right to the use of water is sold in twenty annual installments without interest. In a relatively few cases the owners of the farms do not own a perpetual right attached to the land but rent water annually, but this condition, unfavorable for permanent development, is being done away with.

All irrigation works must be operated and maintained at an annual expenditure, this being a notable item, especially where it is necessary to clean the canal bed and banks of large quantities of accumulated mud, weeds and so-called moss, and to make repairs of more or less temporary structures or to meet extraordinary conditions such as damages from floods or cloudbursts. On the simpler individual or community systems, the cost may be 50 cents per acre per annum, especially where the owners of the canals do the work themselves and are willing to submit to many inconveniences and occasional crop losses. On the larger, better-managed systems where the works are kept in good condition, the operation and maintenance may be from $1 per acre up to $1.50 or $2 per acre each year. In apportioning this charge it should be placed as nearly as possible on a metered basis, the payment for operation and maintenance being in proportion to the amount of water used in order to insure economy. As a rule too much water is put on the ground, and it has been found that the less the amount of water applied, consistent with fair plant growth, the larger and better the crop yields and the less the injury by seepage to the lands in the vicinity.

Economic Consideration. Throughout the arid regions,

which include a great part of the land area of the world, irrigation is essential to agriculture. Its extension should be urged to the limits of the available water supply as made evident by careful research. In the more humid regions where occasional droughts reduce the crop value, irrigation is being practiced as an insurance. The building of works for this purpose has been slow, however, because of the fact that during wet years the tendency is to forget its importance and when drought conditions develop, the time has passed when water can be applied to the best advantage. The extent to which irrigation may be developed in the United States is being studied by the United States Geological Survey through its systematic measurements of streams and researches with underground waters, also by the Reclamation Service in accordance with its organic law.

Not all of the apparently favorable localities can be utilized because of the great expense involved in building reservoirs, canals and other works as compared with present values, but with the settlement of the country and with greater skill and experience acquired in raising and marketing crops there is a corresponding advance in land values and in the ability to pay for expensive undertakings. All of the easy or cheap irrigation schemes have been entered upon; beginning with those which have cost only a few dollars per acre for the water, other projects have been undertaken involving expenditures of upwards of $50 or more per acre. These more expensive undertakings have not proved financially profitable to the investors because of the fact that the values created by the investment in canals and reservoirs have been widely diffused and have not been recoverable by the men who furnished the money. Thus future development in irrigation must rest largely upon obtaining public funds or upon utilizing the credit of the communities which are benefited by the works—the direct losses of interest or of profit on the investment being more than balanced by the indirect gains.

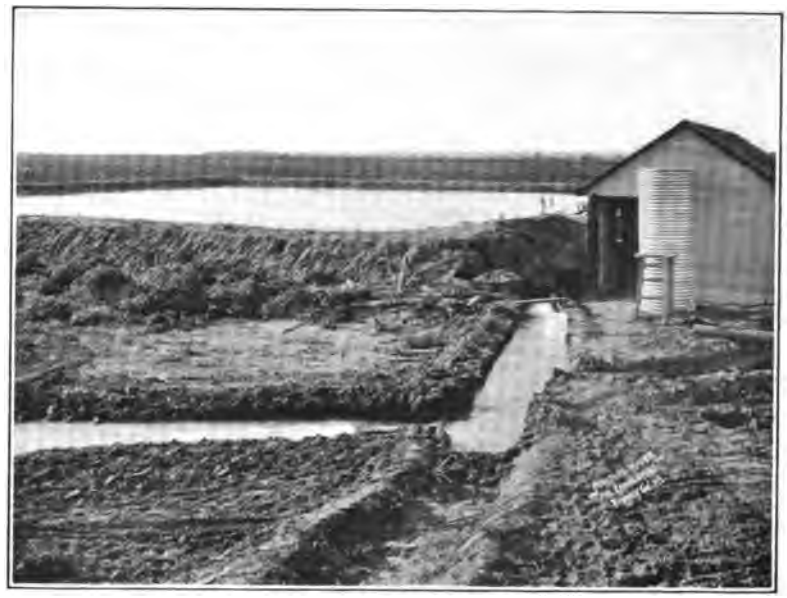


Plate XIII. A.
Underground storage of water in the Great Plains area. Pumping from the so-called underflow near Garden City, Kansas.

Plate XIII. B.
Building canal by wheeled scraper, Boise Project, Idaho.

Plate XIII. C.
Desert land before irrigation, Shoshone Project, Wyoming.

Plate XIII. D.
Alfalfa and hogs, profitable products of the arid region. Sun River Project, Montana.

CHAPTER XII

RECLAMATION INVESTIGATIONS

The vast extent of land throughout the United States whose value is dependent upon the ability to control or secure water, is almost beyond comprehension. Although surveys have been carried on by public and private agencies for many years there yet remain great areas to be examined and the surrounding conditions studied with reference to obtaining an adequate supply of water or of regulating the excess. The problems of rendering these areas useful are by no means easy; their solution rests upon research, upon obtaining fairly accurate knowledge of the physical conditions such as the water supply available at different points, the existence of feasible reservoir sites and the limiting conditions of topography, climate, and soil. There is also another class of items to be considered, namely, the financial or economic, embracing the practicability of utilizing the land after water has been provided or controlled and of disposing of the crops.

The key to the irrigation situation is usually in the water supply and this in turn depends largely upon the questions of economically saving water which otherwise would run to waste. The methods of measurement of the streams have already been described on page 102 and reference also given to the surveys of reservoir sites on page 123. Having these and other related facts, a full study is possible and, as stated previously, the importance of the subject demands thorough research accompanied by the employment of the best engineering ability and experience in constructing and financing the works which may be built.

No two irrigation or drainage enterprises are alike, and each project generally offers a wide range of alternatives in the way

of difficult locations for reservoir or dam, various sources of water to be impounded, height of dam, and selection of the lands to be reclaimed. The economics of future construction, and even more important those of operation and maintenance, are dependent upon the judgment exercised in the preliminary work.

On the basis of the conclusions reached by the first studies the whole physical and financial situation may be considered and adjustment made between the assumed benefits and costs which are to be incurred. As a rule, in nearly all enterprises of this kind, the final cost has far exceeded the original estimates by two or three times the amount at first assumed. This has been due to several causes, but primarily to the many unknown conditions to be met and the tendency to assume that when these unknowns are revealed there will be no surprise. As a matter of fact, the results of investigations are full of surprises—for example, the foundations for proposed dams are frequently found to be far more imperfect than there was reason to anticipate, or after the estimates are completed the price of material and labor has often advanced to a point not previously known.

Another cause of increase of final cost over estimates is the fact that as work progresses there is a tendency to add more details and to depart from the somewhat simple plans at first adopted. There are always demands for larger or more substantial works or for more bridges, water gates or other structures which at first were not considered necessary. Whatever the cause may be of such increase, the lesson to be drawn is that in preparing financial estimates there must be a liberal addition to cover contingencies and an insistence upon adherence to the original plan.

Financing. The financing of irrigation or of drainage projects has been a matter largely of private enterprise or speculation. At first works could be built at relatively small cost because of the fact that the opportunities were almost untouched and there was wide range of choice. The easy undertakings were naturally seized upon by individuals and small ditches and canals built. As the work became more and more difficult, associations were formed and coöperative enterprises

on the part of neighbors were begun. These in turn gave way to stock companies and to corporate efforts.

The first undertakings were largely successful financially because of the fact that most of the work was done by the farmer or landowners; if any misfortunes occurred these were accepted by the community as a matter of course and further efforts undertaken. With the larger projects, however, especially those financed by outside capital, there was often less rigid supervision accompanied by greatly increased cost. There was also a marked tendency to frequent changes as the work progressed, when it became evident that improvements could be made.

The outcome of this evolution was that practically all of the larger irrigation projects, especially those involving water storage, were found to be unprofitable to the investor; while the values of near-by town property were increased, and the construction of railroads and of other enterprises was stimulated, yet the builders of the works did not share in this general prosperity but lost the interest and often the principal on their investment. The only notable exceptions were in cases where the men who built the irrigation works were also owners of adjacent land. In these cases the losses on the works were made up by increase in value of other holdings.

Because of this condition, the taking up of new and large enterprises such as were needed by the country, became neglected and it was only from the passage of the Reclamation Act in 1902 that work on a large scale was again undertaken.

Surveys. Thorough research, scientific and economic, should precede drainage projects. The first work is to initiate surveys and examinations of the country to be reclaimed. The results of these afford the firm foundation of fact upon which the imagination of the engineer may erect in broad outlines the results to be attained. As a rule too little care and expenditure have been devoted to this fundamental matter. There is usually impatience for immediate conclusions and an unwillingness to expend any considerable amount of time and money in these preliminary studies. It is safe to say, however, that within reasonable limits, it is hardly possible to spend too much money on ascertaining the facts of topography, water supply, soil,

climatic, and market conditions. For every dollar thus wisely expended, it may be possible to save tenfold in future construction and operation. If there is any one thing which characterizes the reclamation work of the past and which has led to financial failures, it is the fact that too little time and money have been devoted to research.

There is a wide range of conditions to be studied. Presumably the general location of the lands to be benefited is fixed, but the precise outlines are usually unknown. The question of water supply available for these lands is usually undetermined or the amount of water which must be removed by drainage is unknown. Both of these matters involve a wide difference in possible quantities, and without having a fairly accurate knowledge of these quantities money may be wasted either in building works too large or too small. In case of irrigation works deriving their water from the high mountains or from rolling foothills, it may be necessary to have a quite complete topographical map of the entire catchment basin to ascertain the extent and character of the slopes and to acquire data as to the floods or droughts which may be anticipated. In some countries, as in portions of the United States, good contour topographical maps have been made of many of the catchment basins. These are invaluable in the consideration of the entire project and in the limitations which may be set upon it.

The study of the catchment area and topographical maps showing the principal features tributary to a reclamation project, will usually reveal the opportunities for water storage. There may be a number of alternatives presented, and the merits of each of these should be carefully studied, not only by maps but on the ground itself and with particular reference to underground conditions such as the probability of securing safe and tight foundations for dams.

The topographic surveys of the country from which water may be obtained for irrigation, or of lands to be benefited by such irrigation or by drainage, must be supplemented by a variety of examinations of many related conditions. The best probable location of the works having been determined by field and office study, examinations should be made of the character of

the ground covered or traversed by the works to ascertain the probable cost of excavation of the different materials encountered, the porosity of the soil, its ability to hold or deliver water, or to sustain structures of heavy weight. For example, if a canal should be built along a hillside, especial study should be made as to the practicability of constructing this in the ground or in flumes. Its safety from earth or rock slides, either into the canal or of the entire structure itself, must be the subject of consideration.

Throughout the entire area to be irrigated or drained, both the soil and particularly the subsoil should be examined with reference not only to the probable fertility of the surface soil, but also to the density of the subsoil and its behavior with reference to percolation of water into or out of it. The examinations thus lead into a variety of lines not merely confined to the apparent agricultural values but to the mechanical or even chemical features of the underlying rocks.

Many of the items of research in these preliminary examinations as to the feasibility of a project are of a nature such that the work on them should be continued indefinitely. For example, it is desirable in the preliminary operations to ascertain the rainfall and evaporation at or near the reservoir site. These observations should be kept up even after the works are built, as they afford data needed in the proper operation of them. Also in connection with the behavior of water underground, the height of the water table, both in the irrigated and drained areas, should be noted from season to season and arrangement made for systematically obtaining and recording these facts which show the changes which are taking place beneath the surface.

After the financial arrangements have been completed on the basis of the preliminary examinations and surveys, it usually becomes necessary to make additional adjustments. These final surveys, after the funds have been acquired, are often needed in order to make certain readjustments arising from financial or legal complications. There is usually great pressure on the engineer to prepare the plans and specifications and let the contract as soon as possible after the financial arrangements have

been made, because of the fact that as a rule interest charges begin to run. It is of the highest importance, however, that these final surveys and preparations of detailed specifications be given adequate time, as many economies, as above stated, depend upon the decisions reached regarding alternative methods. There must therefore be a balancing between the demands for immediate construction and the necessity of taking proper time for the exercise of judgment. As a rule the speed with which Americans proceed to the work is the subject of astonishment to foreign engineers, who feel that it is necessary to have a longer time than is usually given in the United States to the maturing of the final surveys.

The results of surveys and examinations are embodied in broadly developed plans usually for consideration of various large alternatives. As a rule, there may be present two or even three or more ways of achieving results, these differing mainly in estimated cost. It is probable, for example, that one plan for a feasible enterprise may involve, for an irrigation work, the reclamation of, say, 10,000 acres at a cost of $50 per acre. A modification of this plan or an alternative proposed may enable the bringing in of 12,000 acres at a cost of perhaps $52 per acre. The question then arises as to whether a somewhat larger cost per acre may be justified in view of the increased acreage which may be utilized. If the enterprise is purely a money-making proposition in which the promoters are concerned with getting back their investment at the earliest possible date, they may prefer the cheaper. On the other hand, if the money is furnished by the public or by semipublic institutions such as irrigation districts, the general benefit to the entire country may justify the larger and more expensive undertaking.

Fundamental questions of this kind can be considered on their merits only when the larger plans have been developed to a point where it is possible to make direct comparison of costs and benefits. For this reason, as before stated, the surveys and examinations must not merely be thorough, but the plans based upon these must be sufficiently broad to permit a full grasp of the situation, and to make adjustments to meet the financial limitations.

DETAILED PLANS. The general plan finally agreed upon as to location and character of works must be supplemented by detailed drawings and specifications such as to enable experienced contractors to bid intelligently upon each of the items involved. It is characteristic of American enterprises, as distinguished from European, for the promoters to push construction even before the plans have been fully matured. There is an impatience for visible results on the part of the investors, whether individuals or the public, which will not brook delay. Wise managers have frequently yielded to these importunities even though they know the final outcome will be unnecessarily expensive. This is not wholly confined to America; in various times and places has been repeated and attributed to popular heroes, ancient and modern, the story of the foreman who "built the bridge before the engineer's picture was ready!" This is an amusing instance of efficiency in saving time in an emergency, but for a permanent work it probably means that future generations must pay several prices for the immediate saving thus made.

There is probably no one place where greater economy can be secured than in the repeated study and the drawing again and again of the plans until a high degree of perfection is reached in all essential details. It is, of course, easy to look back after a structure is completed and see how certain more or less important features could have been modified to advantage. In the case of well-considered works, these savings detected after completion are usually small, but in many instances the responsible men in charge are too well aware that if they had been allowed proper time to plan out all details, they would never have located the works at the place nor built them of the character as finally finished.

STANDARD FORMS. For the execution of any large work of irrigation or drainage there are required plans of almost innumerable smaller structures. For example, in turning water to the irrigated farms, there are required hundreds of small flumes or gates, also many measuring devices, bridges and culverts. Although at the present time the construction of such works has not advanced to a point where, as in railroad

building, there are certain widely adopted sizes and shapes, yet it is practicable to adopt certain standards such as experience is showing to be most efficient.

The Reclamation Service of the United States government is taking the lead in research and in devising standard plans based on studies of the most economical sizes and dimensions, such as of the side slope of canals and drains, bottom widths and velocity for conduits of different kinds. These matters have been worked out for various existing projects, noting the dimensions which have been found most suitable or best adapted to the prevailing conditions. For example, in the case of slopes, the field studies having shown that where the material to be excavated for a canal is relatively hard and not easily eroded, there it may be possible to introduce and use slopes higher than the average employed elsewhere, with corresponding economy in size of cross section of the canal.

The most important matter, however, in considering general dimensions is that having to do with the future operation of the works. In many localities irrigation systems have been planned with the idea of dividing and subdividing water into smaller and smaller streams until each division is accurately proportioned to the needs of the farms to be served. This has been done under the assumption that the irrigators should have a certain steady flow of water from the main system. Later it was demonstrated that greater economy of time on the part of the irrigator, and of water, could be had by turning to him not a small stream but one sufficiently large to irrigate his entire farm in a relatively few hours. Then it was apparent that certain structures and conduits must be enlarged to meet the new conditions. In this case too great care had been devoted to the exact proportion of details and not sufficient allowance made for changes which might take place. Thus at the outset the general dimensions of waterways must be set from a full consideration of the ultimate operating methods and costs.

Construction Methods. The methods of construction must, of course, be adapted not only to the material available,

but to the peculiar conditions of labor which may prevail in the vicinity and especially to the matter of transportation. As a rule irrigation or drainage works, especially the former, are built under pioneer conditions far in advance of actual settlement of the country and of construction of wagon roads or railroads. This is a condition which is not always appreciated by the man who may be inclined to criticise the works after they have been finished and in use. The construction methods which may be necessary at a point fifty miles from a settlement and at a locality to which access can be had only over rough mountain trails, must necessarily be in striking contrast to those alongside of a through line of a railroad, one which may be built after the works are completed and as a result of such works.

The materials to be used under such conditions are limited to the immediate vicinity. If plenty of rock is to be had, masonry may be the best. If the rock is poor, it may be possible to consider concrete, if the cost of bringing in cement is not prohibitive. Otherwise, earth, if available, must be used. This illustrates the point that the surveys and examinations which precede the preparation of any set of plans must be of such character as to answer these points when they come up for careful consideration.

Under modern methods of construction, the greater part of the work is executed under carefully drawn contracts in which responsible builders agree to execute a certain described structure for a definite price per cubic yard or per item specified. In work of a character of which the nature is well known or where the same operation is performed over and over again, it is possible for an experienced contractor to ascertain the cost in advance within narrow limits and to exercise his experience in handling men or materials to secure greater economy, and consequent profits, than his competitors. In proportion, however, as the work is pioneer in character and involves unknown conditions, the preparation of a bid becomes more and more of the nature of gambling upon chances. Thus enter certain disagreeable or even disastrous conditions. There are always contractors more or less responsible who are willing

to take their chances; usually those men who know least about the probabilities of the case offer to do the work at a cost less than that given by the more experienced and safer men. If conditions turn out better than anticipated, they may make considerable sums of money. If, however, unusual storms occur or the rock is found to be of different character than anticipated, the contractor may fail, with consequent delay to the work and increased expense, both in litigation and in securing a new contractor.

It is to the advantage of all concerned to remove as far as possible the element of chance in construction work; in other words, to make the preliminary research and examination as complete as possible. It may be advisable, for example, not merely to make a number of test pits in the soil and to put down drill holes, but also to lay out and build well-planned roads to reach the place of construction, also to open up a considerable part of the foundations which are to be excavated so that the experienced contractor will be able to see from actual operation on the ground what are some of the difficulties to be met. In the meantime, it is often necessary for the engineer in responsible charge to firmly reject offers for work which are made by men of relatively small experience or who propose to experiment with novel machinery or methods. While they may succeed, the probabilities against this are so great that it is not wise to incur the risk of failure and litigation.

In the building of large irrigation works, especially those involving storage reservoirs, the skill of the engineer is thus called into play in many fields, not only in ordinary hydraulic construction but in developing hydro-electric power, in many other mechanical lines and in laying out or executing the work. Experience has shown that wherever the work is of a simple character such that it can be easily described, as, for example, the building of earthen canals, the contract system is most economical, but where unknown difficulties are involved, such as the excavation of foundations in a new or remote country, where the unexpected is likely to happen, then under present conditions it is more economical to carry on operations by what is known as force account. Under this system the work is

supervised and directed by the engineer and the plans may be modified day by day to fit the conditions—thus securing under wise management the highest economy as well as efficiency.

CHAPTER XIII

IRRIGATION STRUCTURE AND METHODS

Divisions of an Irrigation Project. Most irrigation systems may be considered as divided into several portions or units.

First, the collecting unit, consisting of reservoir or other devices, such as wells and pumps, for obtaining the water;

Second, the diversion unit, which includes the dam in the river at the head of the main canal.

Third, the carrying or trunk line canals.

Fourth, the distribution, taking in the minor canals which carry water to the fields.

By making such a division of parts and of expenditures incurred on each, it is possible to make comparisons between irrigation systems of different size and character. Many do not have reservoirs, but derive their supply directly from the streams. In such instances it would not be profitable to make comparisons with the entire cost of a system which does include a reservoir.

In other cases the carriage portion is negligible because of the fact that irrigation of the dry lands begins at a point immediately below the headworks; in other instances there is a long main canal, built at large expense on rocky hill slopes, to carry water to remote tracts.

Comparison of cost of construction, operation and maintenance of small irrigation systems which have no storage nor main canal is thus made possible with similar costs of the distribution portions of larger enterprises.

Collecting Unit. A description has already been given of some of the notable reservoir and other devices for collecting water for irrigation, notably on pages 153 to 175, together with brief statements of methods of constructing dams, also details of some of the larger works already built. A comparison of

the cost of these works yields many points of interest, especially in considering the value of the results and the magnitude of the work already undertaken, also by inference the large investment which must be made in the future in connection with other projects which may be found to be practicable.

Diversion Unit. Next in importance to these dams built for the purpose of creating storage reservoirs are the somewhat similar structures erected for diversion of water from the stream channels into the main canals. Some of these act as combined storage and diversion works, but the characteristic feature of a diversion dam is the fact that it is a necessary adjunct to the headworks of a canal or to the carrying system for an irrigation project.

Diversion dams as a rule differ from storage dams in that they are relatively low and are located in or across the main drainage lines, being thus subject to overflow. As a rule there is accumulated against them the debris carried by the river, and the pond or storage capacity at first created by building the dam is destroyed in a few years by this accumulation. The original or simplest type of diversion dam consists merely of bowlders or rocks placed across a river or diagonally upstream into the current. In times of low water a relatively tight barrier is thus built of stones and dirt with brush or boughs of trees. Following the development of the country and the necessity for more permanent structures, low solid masonry dams or sills have been built or walls of concrete—these in turn being replaced by more carefully designed overflow dams, raising the water to still greater height and permitting the construction of higher canals.

The proper uses of the waters conserved by storage in the reservoir previously described are made possible in many instances by providing these subsidiary or secondary dams, built across the streams, not for storage, but for raising the water or controlling it so that it will flow into the head of the main irrigation canals. One of the best examples of such a structure is that shown in Pl. II. D, which is built across Salt River, Arizona, and serves to divert the water stored and released from Roosevelt Reservoir. This dam is 38 feet high and 1,000 feet

long, the river in flood overflowing the entire crest. As will be seen in the view, canals head at each end of the dam, that on the north side, in the foreground of the view, being the Arizona Canal with capacity of 2,000 cubic feet per second and 22 miles in length. In the distance is the South Canal with capacity of 1,200 second-feet.

Another dam similar in character is the Whalen in eastern Wyoming on North Platte River. (See Pl. XIV. A.) This is 29 feet high and 300 feet long, the floods pouring over the entire length of the crest as shown in the view. In the foreground is the Interstate Canal with capacity of 1,400 second-feet and a length of 95 miles. On the opposite side of the river is the head of the Ft. Laramie Canal, 1,430 second-foot capacity, and 26 miles long.

In the planning of a diversion dam, it is customary to place the gates at the end of the dam in such a way that the water will be taken out almost at right angles to the flow of the stream as in the above-described views. By arranging sluice gates in the dam, it is thus possible during high water to scour away any sand or gravel which may accumulate in front of the canal head gate.

Carrying Unit. Starting out from the diversion dam is the main canal with its control gates and spillways. It usually winds along in a general course nearly parallel to that of the river until with less grade than that of the natural stream it has succeeded in reaching an altitude where it can swing away from it along the edge of the valley land. Sometimes two main canals are thus built, one on each side of the river. These may continue for many miles before reaching any considerable area of agricultural land. There they usually divide or branch to cover the principal body of the farming area. The number of miles of main and branch canals traversed by the water before reaching the irrigable lands varies greatly with the different systems.

For the purpose of comparison, it has been found desirable, as before stated, to distinguish this part of the irrigation system, beginning at the diversion dam and extending down and including the main and principal branches, as the carrying

system. It is composed of relatively large canals, deep and narrow when in solid rock or sidehills, and broad and shallow when out in the open plains and built in ordinary earth. The cross section thus varies from place to place, dependent upon the ground in which the canal is built and upon the slope which may be given. Usually there is need of keeping the altitude of the canal as high as possible, reducing the fall per mile to the minimum of a foot or less, thus necessitating a large cross section. Occasionally, however, especially where the canal first leaves the river, the condition may be such that greater slope can be given and the cross section reduced; in some cases it is lined with concrete to produce the greatest velocity and quantity of discharge in the smallest amount of excavation.

At each diversion dam are gates or controlling works permitting water to enter the head of the main canal. Immediately below these gates are usually devices for permitting the water to flow back to the river in case of accident and to scour out any sediment deposited below the gates. An automatic spillway is shown in Pl. XIV. A—in this case it is placed adjacent to the dam, but usually such a device is located a mile or so farther down the canal if the topography of the ground permits.

In the first few miles below the diversion dam the location of the main canal is necessarily near the river and often on steep hillsides. Occasionally it is necessary to pass it through tunnels or to line it as shown in Pls. XII. C and XIV. B. After getting clear of the river, however, the construction is usually in open, somewhat rolling, country, and is in earth where the operations are relatively simple of execution. This is illustrated in Pl. XVII. A and Pl. XIII. B, the latter showing excavations by plowing and scraping and building up of a high bank on the lower side of the canal, in general appearance resembling a railroad grade, the chief difference being that earth is carefully compacted as it is deposited.

It frequently happens that the main canal is not built of full size when first constructed because of the fact that for many years there will not be demand for enough water to fill the canal. Under such conditions, enlargements must be made

from time to time. Usually this work is done after the end of the crop season, when water can be taken out of the canal, but where the irrigation season is long or continues practically throughout the year, as in Arizona, it is desirable to enlarge the canal while water is flowing in it.

Distributing Unit. An irrigation project may be so fortunate as not to need any storage works and the topography of the country may be such that its carrying system is insignificant; but in all cases the distribution is a vital point. While apparently simple, in that it consists of miles of smaller canals and ditches located according to the slope of the country, yet in practical operation the distributing system involves more detailed problems in proportion to the cost than do the works for the storage or carriage of water. It is usual for the highest engineering skill to be employed in the planning and building of a great dam or large canal. Unfortunately the same degree of skill has rarely been utilized in laying out the distribution conduits. Hence, it has come about that in the actual operation an unnecessarily large number of difficulties and sources of expense have frequently arisen, more than should have occurred had the system been planned by men thoroughly acquainted with the problems of handling the water to the farms.

The condition is similar to that in railroad locations where the early railroads were built mainly with reference to construction cost. Now, with larger experience, the ease and economy of construction are kept secondary to the requirements of operating, since these go on forever while the construction costs are only for a short period.

The distributing system consists of the so-called laterals or smaller canals taken from the side of the main or branch canals. The distinction is purely arbitrary and yet is one of importance. The laterals should be planned and built not only to command the largest possible area, but to permit the most economical handling of the water to the farms. If too small, it is not possible to serve the lands rapidly, and if too large, the channels become choked with weeds or mud and introduce unnecessary cost in cleaning.

The main canals soon after reaching the irrigable lands

Plate XIV. A.
Whalen diversion dam of North Platte Project, Nebraska-Wyoming.

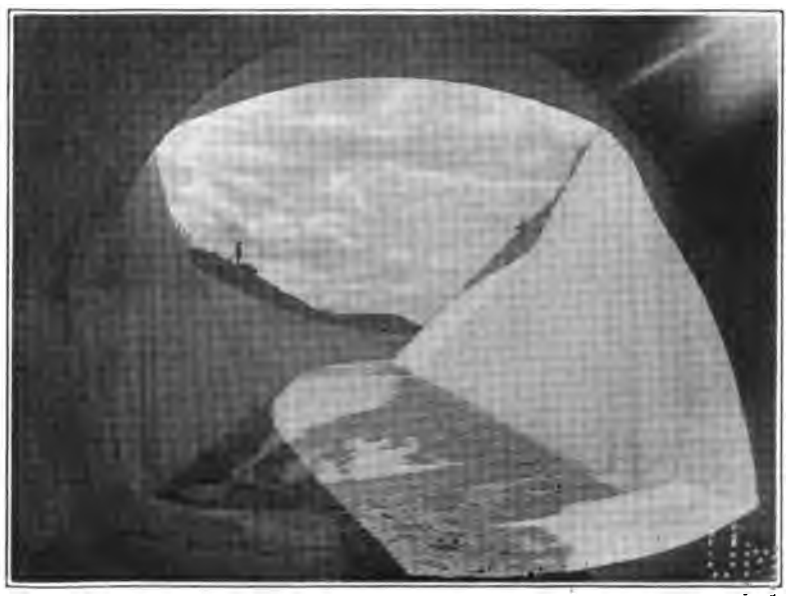


Plate XIV. B.
A lined tunnel with approach to canal. Grand Valley Project, Colorado, capacity 1,425 second-feet.

Plate XIV. C.

Farm lateral delivering water to furrows, using canvas dam, Shoshone Project, Wyoming.

Plate XIV. D.

Using water, stored by Roosevelt Reservoir, for irrigation of young orange grove, applying it by furrows. Salt River Valley, Arizona.

begin to divide and send off branches, these in turn delivering water to smaller canals or laterals. At each point of division it is necessary to provide suitable gates or control works so that the proper amount may be admitted to each lateral, the quantity being regulated from day to day in accordance with the demands of the farmer. A view of one of these laterals is shown in Pl. V. B and another in Pl. XVI. A. Such laterals in turn divide and finally deliver water to what are known as the farm laterals, these being of a capacity sufficient for one or two separate farms. In Pl. XIV. C is shown one of these small farm laterals taking water for the first time to desert land, soaking it thoroughly and permitting cultivation. Water is usually turned from the farm laterals either by small wooden gates or by temporary dams of wood or canvas as can be seen in this picture. A hole in the bank is dug with shovels and, when no longer needed, is quickly filled. The farm laterals in turn take the water to each field or tree as shown in Pl. XIV. D.

STRUCTURES. In connection with the carrying and distributing of the water which has been diverted in the irrigation canals, almost innumerable structures are needed. The more important of these are described in the following paragraphs.

FLUMES. Care is taken in laying out the laterals to keep the water flowing on as gentle a grade as possible and thus to reach the highest spots of the farm lands. Even with the greatest ingenuity in fitting the topography, there are occasional conditions where water must be carried across a depression. This is usually done by some form of open flume, the older and cheaper of wood, others of metal. Concrete is also used, as in the long conduit which takes the water of the Tieton River in Washington, shown in Pl. XV. A, the flume winding along the hillside. This is composed of short concrete sections, cast in suitable steel forms, the work being done along the valley where it was possible to obtain sand, gravel, and water for mixing the concrete. This plan was adopted because of the fact that the space on the hillside suitable for work was so constricted that it was not found economical to excavate and build a lined canal—especially as portions of the work are along almost vertical cliffs and in places the canal passes through tunnels.

A view of the separate pieces of the canal is shown in Pl. XV. B. The steel forms have been removed from these. As soon as these had become completely dry, they were hoisted and carried by overhead conveyors and by short pieces of construction track to the point where they could be swung into place and the joints cemented together to make the continuous line shown in Pl. XV. A. The capacity of this is 300 cubic feet per second, and the length is 12 miles.

TUNNELS. On steep hillsides it is often economical to put the canal underground through a tunnel. Occasionally also the line can be shortened by piercing a projecting point of rock. In consideration of maintenance, the reduced economy may justify a larger increase in cost in the building of a tunnel as contrasted with an open canal or flume which is likely to be disturbed by rock or snowslides from the upper slopes. It is usually necessary to line the tunnels and for this purpose concrete is generally employed. A view looking out of such a tunnel is given in Pl. XIV. B, which also shows the concrete lining of the main canal of the Grand Valley Project and the warped surface of the gradual transition from the tunnel to the section of the canal. In the work of the Reclamation Service, a large number of tunnels have been built for irrigation purposes, the aggregate length of these being 157,000 feet.

SIPHONS. In order to cross depressions, it is usual to carry the canal over on grade, using for this purpose flumes as previously described. Occasionally, however, it is more advantageous to drop the canal and carry it in some form of pressure pipe under a depression, especially if the latter is subject to extraordinary floods. Such condition is shown in Pl. XV. C, which illustrates the concrete siphon on the Interstate Canal from North Platte River, Wyoming-Nebraska. This consists essentially of a large concrete box, rectangular in outline, depressed below the level of Rawhide Creek, a tributary of North Platte River. The canal water descends into this inverted siphon, passes under the bed of the creek and then is conveyed up nearly to the original level by a continuation of the watertight compartments.

Most of these siphons are built during dry weather by exca-

vating the ground and then covering them up so that the flood can pass over undisturbed. Occasionally, however, conditions are such that it is necessary to tunnel under the stream as, for example, at Yuma, Ariz., where the main canal from Colorado River coming south on the California side, crosses under the river to the Arizona side. The river channel at this point is quite deep and is filled largely with soft mud which scours out in time of flood. It was found to be advisable to go to a depth of eighty feet or more beneath the river level in order to construct the tunnel.

Canal Lining. Ordinary irrigation canals and laterals are excavated for the most part in loose surface soil. Often this consists largely of sand or gravel, and wherever these form the bottom or sides of the canal, there is great loss of water by percolation or seepage. Where water is scarce, this loss becomes an important item, moreover if the canal is located on a sidehill the seeping water may tend to cause slides with resulting great damage, due to the sudden escape of large volumes of water. It is, therefore, important to line some of the canals not only to save valuable water, but also to insure safety. With improved methods and reduced cost, the placing of lining, particularly of concrete, is increasing. In the larger canals, the concrete may be made of six inches or even more in thickness. It is laid in a manner similar to that used in the construction of concrete roads or pavements. In smaller canals, the lining is frequently much thinner; if the soil is firm it may be less than one inch in thickness, being plastered directly upon the sides and bottom. In Pls. XII. A, XII. C, and XIV. B are shown portions of lined canals.

In many localities where the irrigation water carries a considerable proportion of sediment this muddy water may be controlled in such a way as to cause deposits to form along the sides and bottom of the canal effectually sealing up the smaller crevices or filling the interstices between the grains of sand or bits of gravel. Thus it may result that after one or two seasons a canal which at first lost a great part of the water becomes capable of delivering each year a larger and larger proportion of the amount received at the head. When the water is clear

such action cannot take place and there it is sometimes necessary to bring clay to the spots where the greatest seepage occurs and make a clay puddle or lining throughout the sandy or gravel portions. In the canals of the Minidoka Project, for example, in southern Idaho, there appeared to be at first a loss of 75 per cent, only about 25 per cent of the water carried being ultimately delivered to the irrigated lands.

The country through which this canal flows is quite sandy and the water, being taken from Lake Walcott on Snake River, is clear. There is little clay in the vicinity which can be obtained by ordinary methods and taken to the canal, but an ingenious scheme was adopted by the engineers in which to meet this condition, as noted on page 100. Water was conducted to certain deposits not far away and a portion of the clay washed out, being conducted by flumes to a point, Pl. IV. D, where the fluid mud could be dropped into the canals. The mud thus introduced serves to check the seepage loss. It has also another and somewhat unforeseen result in that the canal itself was made smoother, permitting greater velocity for a given slope, or in other words reducing the value of n in Kutter's formula—in one case from 0.020 to 0.016, the canal having a capacity of approximately 700 second-feet.

The reduction of seepage loss was shown not only by the saving of water but by the fact that wells driven near the canal have gradually lowered or become dry due to the cutting off of their supply from the canal. The distribution of silt thus put into the clear canal water has been quite general, from two to five times as much being deposited on the slopes as on the bottom. On the curves, the deposit, as might be expected, is largely on the inner slope; but even on the outer slope the percolating waters have carried fine particles of clay into the banks and have to this extent clogged the passage of water through them.

In order to retain the silt in places where exposed to the wind, or where the velocity is excessive, sagebush covered with wire netting has been used. In the case of this canal approximately $25,000 was expended in putting silt into the canal. This amount, while apparently large, is small in comparison with

the advantages gained in reducing the amount to be expended on drains to take away the excess water. Comparing it with the cost of obtaining water for the canal, it may be said that if only ten cubic feet per second of water was saved, the value of this saving would justify the expenditure above named.

GATES. To control the water there are required an almost infinite number and variety of devices from the simple plank or stop log used by the farmer, Pl. XVI. A, to the elaborate concrete and steel gates shown in Pl. XIV. A. Most of these slide vertically in grooves, but to meet certain conditions other devices are employed, particularly the circular gate which can be used on the end of a pipe of metal, concrete or tile. One of the latest devices, the cylindrical gate on the Franklin Canal in El Paso, Texas, is illustrated in Pl. XV. D. This canal takes water from the Rio Grande a short distance above the dam shown in Pl. VIII. D, near the city of El Paso, and carries it in a general way parallel with the stream to lands below the city. It has a capacity of 450 second-feet and a length of nearly 32 miles.

AUTOMATIC SPILLWAY. On every large canal there is likelihood of an extraordinary rain or cloudburst sending water into the canal so rapidly that the banks may be overtopped. Great loss of property or possibly of life might result from the cutting of the canal banks. To prevent this, various devices have been tried, particularly of gates which can be operated quickly by one man. It is not safe, however, to depend upon the man being on hand at times of extraordinary storm or other catastrophe and efforts have been made to perfect a simple and automatic device. One of these is so constructed as to have a portion of the lower canal bank protected by concrete, the top of this being placed at the safe water height. If for any cause an excess of water comes into the canal tending to raise the surface above the level of the concrete wall, it immediately spills over into a side channel from which it can flow away to the river without injury. When the manager desires to raise the water level and to increase the flow of the canal temporarily, a row of bags filled with earth or some similar devices can be placed

on top of the concrete, being so arranged that these are readily washed out if the water goes above a certain altitude.

Drops. Efforts are made to keep the canals on a very gently descending grade so that the velocity will not exceed as a rule two to three feet per second. If the country falls off rapidly, it is necessary to make some provision for letting the water down without increasing the canal grade and consequent velocity to an extent to erode the channel. For this purpose many wooden structures have been built, but for permanence concrete is now more usually employed.

At the lower end of these drops there is opportunity for the development of power. The chief objection to making expenditures for water wheels and electric generators at these points is the fact that the canals are in use only during the crop season and thus do not furnish power throughout the year. If, however, a demand for the power can be found which is coincident with the time of the use of the canals, then this objection is removed.

Such coincidence occurs if the power can be employed for pumping water for the irrigation of lands which cannot obtain a gravity supply from the canals. During the height of the crop season, when most water is flowing in the canal and most power can be developed, there is corresponding need of this power to procure additional water. There is thus offered to the engineer the opportunity of producing conservation not only of the water but in the employment of power which would otherwise be wasted. Examples of this are to be found in the Yakima Valley in the state of Washington, where water in various canal drops is employed in creating hydro-electric power which, transmitted to a distance, enables lands which otherwise would remain arid to be successfully irrigated. On the Huntley Project in Montana the drop in the main canal is utilized for lifting water to lands above the level of the canal. In this case there is no electric transmission of power, but the pump for raising a portion of the water is placed on the upper end of the vertical shaft carrying the water wheel which is driven by the descent of the main body of water.

Pumping. A relatively small percentage of the irrigated

lands of the country is furnished with a water supply by pumping; but this small percentage affords many interesting and valuable lessons because of the fact that with the high cost of obtaining water by this method, there is enforced corresponding economy in its use. Hence are presented striking examples of the excellent results which may be obtained by the application of a small quantity of water and a demonstration of the fact that it will be practicable to greatly extend the area irrigated whenever the irrigator using the gravity supply is as careful as his neighbor who depends upon the more expensive pumped water. In other words, if the water to all of the 95 to 97 per cent of the arid lands now furnished with gravity supply was handled with a skill and economy comparable to that used in the areas to which water is pumped, far greater crops could be raised and the areas irrigated might be doubled or trebled. More than this, if in the future expenditures are made for water storage on a scale comparable to those incurred in the pumping, there will be a great increase in the number as well as the cost of reservoirs yet to be built. In short, a study of results obtained by pumping reveals to the engineer economies and possibilities of a vast extension of hydraulic development.

Pumping has been resorted to in localities where it has not been practicable to bring water to the farms by gravity; for example, along the shores of lakes or the banks of rivers whose fall is too gentle to permit diversion by gravity. The cost of water per acre supplied by pumping far exceeds that of the gravity supply and in fact when these costs have been ascertained, with proper allowance for interest and depreciation, the figures have usually exceeded the anticipations of its most enthusiastic advocates. Roughly stated, the cost of lifting one acre-foot of water one foot in height by ordinary small engines is about 7 cents; or to lift this amount of water 50 feet would require $3.50, irrigating an acre to a depth of one foot. This is at least three times the cost of gravity supply. In the case of orchards producing high-priced fruits, it is possible to pump water profitably or even to elevate it for alfalfa lands with a lift of from 50 to 100 feet and upward. In the case of more

valuable crops, such as cane sugar in the Hawaiian Islands, water has actually been raised to a height of over 500 feet.

With large economical pumping plants, the cost, including depreciation and repairs, may be reduced as low as 3 cents per acre-foot raised one foot or even less; but the margin of profit in the ordinary farm crops is so small that the average irrigator can rarely afford to pay the cost of pumping water to a height exceeding, say, 50 feet.

In portions of California and other fruit-growing localities, considerable areas of land are being irrigated by water obtained from wells. The supply of ground water throughout the arid region is, however, quite limited. (See in this connection pages 81 and 90.) It is necessary in some localities to go to depths of from 100 to 300 feet or more before reaching moisture. There is always probability that the supply even at this depth will be limited and that by constant pumping the water level will be lowered. Such, for example, has been the case in the valleys of southern California where with rapid increase in the number of wells the accumulated supply has been rapidly drawn down, especially after a series of dry years. Some of these wells are so situated that the seepage from adjacent foothills tends to replenish them.

Where the supply of water from wells is ample, various devices have been employed, such as windmills, gasoline and steam engines, and electric power, for bringing it to the surface. It is very important that the well borings be continued down into and through the water-bearing sands or gravels, so as to take advantage of the full thickness of the pervious deposits. Perforated pipe is often driven into the layers of coarse gravel, adding greatly to the capacity of the well.

Artesian conditions (see page 81) occur in limited areas in nearly every state, but they do not furnish a notable supply for irrigation, excepting on the Great Plains and in parts of California. Wherever they occur the water has especial value on account of the convenience incident to its rising above the surface. In some places, as the James River Valley of South Dakota, the pressure is 100 pounds or more to the square inch, throwing the water to a considerable height and enabling the

wells to be used as sources of power. The quantity of water to be had from deep wells is governed by the diameter of the well, the structure and thickness of the water-bearing rocks, and the pressure sustained by the water. With relatively dense rocks a slight head of water will throw only a feeble stream, but from thick layers of open gravel or sand rock large volumes are delivered. It frequently occurs that a four-inch pipe will deliver all of the water which can reach this point, and increasing the diameter of the well will not alter the flow.

An important source of power for pumping water is the wind. Over the broad valleys and plains of the arid region, the wind movement is almost continuous for days and weeks. It is a comparatively simple and inexpensive operation to sink a well into the water-bearing strata and erect a windmill, as illustrated in Pl. IV. A, attaching this to a suitable pump. A windmill once erected on the plains is operated day and night by the wind, bringing to the surface a small but continuous supply of water. This small stream if turned out on the soil would flow a short distance, then disappear into the thirsty ground, so that irrigation directly from a windmill is usually impracticable.

To overcome this difficulty, it has been found necessary to provide small storage reservoirs or tanks, built of earth (as shown in Pl. IV. A or better in Pl. XIII. A), wood, or metal, to hold the water until it has accumulated to a volume sufficient to permit a stream of considerable size to be taken out for irrigation. Such a stream, flowing rapidly over the surface, will penetrate to a distance and cover an area much greater than is possible with the small flow delivered by an ordinary pump. One disadvantage connected with the use of windmills is that most of them are constructed to operate only in moderate winds. As the strength of the wind increases, the wheel begins to revolve, increasing in efficiency until the velocity of the wind is about eight or ten miles an hour. At greater speed the mills are usually so constructed that the efficiency decreases rapidly as the wind becomes more powerful. When it approaches a gale, the mill stops completely.

Although there are in use large numbers of windmills in

pumping water for irrigation of small tracts, the aggregate area is small compared with the extent of lands watered by more powerful devices, such as those made possible by the development of hydro-electric power. Within the past decade much attention has been given to this matter, particularly in connection with the use of power developed for municipal and manufacturing purposes and which is available for farm use at seasons or times of day when not needed for the principal industry. It is possible at such times to obtain power at low rates and to utilize it in pumping water for agricultural purposes.

CHAPTER XIV

OPERATION AND MAINTENANCE

The object of providing water by storage in connection with irrigation is, of course, to have it available whenever needed. Such need is continuous throughout the irrigation season; it is vital for crop success that the canal be operated and maintained by an adequate force of skilled men employed for the purpose, and in such a manner as to have the water at hand as needed. The cost of operation and maintenance is dependent largely upon local conditions and upon the way in which these have been met in the original construction, notably with reference to permanence.

In planning and constructing any works for irrigation and drainage, the first requisite, as above noted, is that when built these may be operated and maintained at reasonable cost. While temporary expedients may be necessary at times, yet full consideration should be given to the future difficulties involved; the plans when under consideration should be prepared or passed upon by men who have had large experience in the operation and maintenance as distinguished from the more purely engineering or construction side. All these works are built for indefinite use and are to be maintained presumably as long as civilization endures. The development of the resources in the country and the location of industries are intimately connected with the irrigation or drainage works and any error made in these may be indefinitely perpetuated with subsequent loss to all concerned.

In the case of drainage works, the operation is practically automatic and the maintenance should be extremely small, consisting in seeing to it that the drains are not clogged and that the inlets and outlets are properly protected. In the case of irrigation, however, where water should be measured and deliv-

ered at short intervals through a great part of the year, it is necessary to have a carefully organized force of experienced men giving attention to all of the details of the control and diversion of water.

The operation details consist largely in making deliveries of water to each farm as needed. The older canals were so arranged as to furnish a continuous flow of water, but this had the ill effect of encouraging large waste and of ruining much of the agricultural land.

Under modern methods provisions are made by which each farmer notifies the water master either by telephone or card as to the time and amount of water needed. From such notices a schedule is prepared so that the water may be turned into the laterals and delivered to the farms at a time determined upon in advance. The keeping of the records of the amount actually received into the main canal, distributed to the laterals and turned out to each farm is a matter of first importance.

The maintenance operations consist in keeping the canal in good condition. The work is usually done by the same men who are employed in operation details—the maintenance work being performed after the close of the irrigation season or at times when the canals are not in use. Among the problems of maintenance are those of keeping the banks clean and free from weeds. Some of these, like the so-called "tumble weed," when dry are blown into the canal and obstruct the flow, occasionally causing bad breaks unless carefully guarded against. An interesting method of cleaning canal banks has been tried in the Salt River Valley in Arizona where sheep have been utilized, these browsing along the banks and eating down the herbage. A view illustrating the action of the sheep is shown in Pl. IX. A, where a band is grazing in the vicinity of Huntley, Mont.

Measurement of Irrigation Water. In the older and smaller systems where the manager has grown up with the work, it is possible for some one man or group of men to carry in mind all of the details and to apportion the water fairly well to the relatively few water users, but in the modern large system built to supply water to hundreds of farms this easy-going way is no longer applicable. The condition may be compared to

that of the country merchant who, knowing his people, can apportion among his customers a pile of coal or of wood roughly by his eye and with reasonable satisfaction. When, however, he must delegate these details to others, and he can no longer know of each transaction, to avoid difficulty and bankruptcy, he must maintain a thorough system of weights and measures and make record of each transaction.

So it is with the measurement of irrigation water. The older managers naturally resented the introduction of troublesome details of measurement and asserted that for all practical purposes their methods are best. A study of these, however, shows that there has been great inequality in irrigating streams supposed to be of the same volume, and enormous waste of water resulting in ruin to large areas of land. The only way in which such injurious conditions can be prevented is to keep a record of the water available in the storage reservoir, also the quantity received in the main canal and divided to the principal branches, and more than this the time and amount of water turned to each farmer. Having these details, it is possible day by day to ascertain where the water goes and the quantity of waste, and to check up against the acreage the beneficial use of the water. When once a proper system has been installed, the advantages as compared with the costs are so great that no one seriously advocates a return to the old haphazard method.

The measurement of the water is one of the most important functions of the operating force. Pl. XVI. A illustrates one of the laterals with the small wooden turnout gates at the head of each farm lateral. The water master or his assistant visits each of these gates daily, sets them to receive a certain amount of water, makes records of the fact, and if necessary locks the gates to prevent unauthorized changes.[1]

Heads of Water. The amount of water which any one man can economically apply to his fields varies according to the skill of the farmer, the soil, the crops, and especially to the care with

[1] Adams, Frank, "Delivery of Water to Irrigators," United States Department of Agriculture, Office Experiment Stations, Bulletin 229, 1910.

"Some Measuring Devices Used in the Delivery of Irrigation Water," University of California Agricultural Experiment Station, Bulletin 247, 1915.

which the surface has been leveled. The tendency has been to progress from the use of relatively small streams or heads of one cubic foot per second up to three or four times this amount or even to ten or more second-feet, an amount which the older irrigators would regard as absolutely impossible of control. With larger heads there result quicker irrigation and the application of a proportionally less amount of water for the area to be covered; also larger crop yields per unit of water applied.

Application of Water. The methods of irrigation practiced in various parts of the United States differ according to the climatic conditions and soil, and especially as to the early habits or training of the irrigators. While the methods of conserving and conveying water have improved under the stimulus of modern invention, there has been little progress in the development and use by the farmer of well-considered ways or economics in putting water on the fields. The various methods employed can be classified in general under one of three ways—flooding, furrows, or subirrigation.

Flooding. The irrigator in flooding his fields turns the water from a lateral or distributing irrigation ditch over the nearly level land and completely submerges it. Perfectly level fields are, however, comparatively rare, and the first step in primitive agriculture by irrigation has been to build a low ridge around two or three sides of a slightly sloping field, so that the water is held in ponds. These low banks are commonly known as levees or checks. In construction they are frequently laid out at right angles or more often following the contour of the ground, dividing the land into a number of compartments. Water is turned from the irrigation ditch into the highest of these compartments, as shown in Pl. XIV. C; when the ground is flooded, the bank of the lower side is cut or a small sluiceway opened, and the water passes into the next field, and so on, until each in turn is watered. So-called "wild-flooding" is also practiced in some localities, the water being diverted in such a way as to flow in a series of small rills or a thin sheet over the gently sloping area. Considerable skill is required on the part of the irrigator to avoid swamping one part and leaving dry another portion.

Furrows. Irrigation in checks has gradually decreased in relative importance, owing to the expense of leveling and levee-ing the ground. With experience the irrigator has become able to apply water to crops which are cultivated in furrows without resorting to such expensive means. The furrows are plowed in such a direction that the water when turned into them from the lateral ditches will flow freely down them without washing away the soil. When the water has completely filled the furrows, Pl. XVIII. A, and has reached the lowest points, the little streams are cut off and turned into another set. The methods of doing this differ; sometimes the irrigator simply cuts the bank of the distributing ditch with a shovel and then closes the opening after sufficient water has escaped, as illustrated in Pl. XIV. C. A more systematic method is employed in California. Water is carried to the upper end of the furrows in a small box flume with openings about one inch square in the side. These openings are closed by shutters and a number can be opened at once, permitting a certain quantity of water to escape into each furrow.

The slope given the furrows determines to a certain extent the amount of water received by the soil. If the fall is very gentle, the water moves slowly and a large portion is absorbed while the furrow is being filled. If steep, the water quickly passes to a lower end and the ground does not absorb so much. When the entire field has been watered, the furrows are usually plowed out and a thin layer of the soil stirred to make an open, porous covering or mulch, as in Pl. XIV. D, preventing excessive evaporation and allowing the air to enter the ground. Without such cultivation a hard crust may be formed. The loosening of this crust breaks the capillary connection with the moisture beneath and thus lessens the loss of water.

For irrigating small grain, the fields, brought to a uniform surface, are thoroughly cultivated, and after the grain has been sown, parallel lines are made similar to furrows, but smaller and nearer together. These are laid out in the direction of the desired slope, so that the water can flow down the marks through a cornfield. The rapidly growing grain shades the surface and prevents the formation of crust, rendering sub-

sequent cultivation unnecessary. In order to cause the water to spread from the lateral ditches into the furrows through the ground, use is made of a canvas dam, Pl. XIV. C, or a tappoon —a small sheet of metal of such shape as to fit across the ditch. This can be forced into the soft earth, making a small dam and causing the water to back up and overflow the field of grain.

Furrow-irrigation is usually employed in watering trees and vines, as shown in Pl. XIV. D. In some localities, however, basin or pool irrigation is practiced. Where water is especially scanty and correspondingly high priced, the supply is conducted in cement-lined ditches and by wooden flumes, and is then turned out into the furrows plowed around or as near as possible to the trees and vines. The water issuing from small apertures in the side of the wooden box falls into the furrows and is immediately conducted to the vicinity of the growing plants. Care is usually taken that the water shall not actually touch the tree trunks, as in Pl. XIV. D, and that it reaches the extremities of the roots to encourage these to spread outward. After the water has traversed the furrows to the lower end of the orchard, the supply is cut off, and the ground is tilled as soon as the surface dries sufficiently.

Subirrigation. Attempts have been made to conduct the water beneath the surface immediately to the roots of the trees, thus preventing waste by evaporation from the surface of the ground. Few devices have been successful, owing to the fact that the roots of the trees rapidly seek and enter the openings from which the water issues, or, surrounding the pipe by a dense network, cut off the supply. Porous clay tiling has been laid through orchards, and also iron pipes so perforated as to furnish a supply of water along their length. In some orchards where subsurface irrigation has been unsuccessful because of roots stopping up minute openings beneath the surface, the system has been reconstructed and water has been brought to the surface at or near each tree by means of small hydrants.

The term subirrigation is occasionally applied to conditions occurring in nature where water percolates freely beneath the ground for a considerable distance, sufficiently near the surface to supply the need of crops. Where the subsoil transmits water

freely, irrigation ditches may subirrigate large tracts of country without rendering them marshy. Thus farms may obtain an ample supply of water from ditches half a mile or more away without the necessity of distributing small streams over the surface. In the San Joaquin Valley, California, vineyards in certain localities are thus maintained in good condition, although water has not been visibly applied for many years.

Rotation of Flow. In the pioneer days of irrigation in the United States it was customary for the farmers to receive a small, steady flow of water—one which could be turned to a field, the gate set, and the farmer proceed about his business or at night go to bed and in the morning see what had happened. If everything had continued as anticipated, the water in time would reach the end of the field and while the upper portions were overirrigated, the lower part would have a small supply. Often, however, especially during the night, the stream became obstructed or a wind storm diverted it. As a result there would be a pond in one place and dry spots in another. With the increasing need of more water for additional lands and the demand for economy, there came about a realization of the fact that a larger area could be irrigated by using the water more carefully, especially by giving personal attention to the flow and utilizing larger streams for shorter times. There thus arose the custom of two or three neighbors combining in one head or stream the quantity of water to which each was entitled and using this in succession, shutting off the flow when not needed and turning the supply over to another neighbor, and so on, applying the water at intervals of a few days and doing all of the watering of one field in a few hours.

One of the disadvantages of this rotation is that the water must be taken and used irrespective of the time of day or night and if an irrigator's turn comes in the evening, it may be necessary for him to work most of the night by the light of a lantern, to get the water over the field. Some, skilled in details, prefer the night irrigation, as they think that the water goes farther and better. With everything prepared they can work through the cool night with greater comfort. Others naturally object and the introduction of rotation in countries where there has

been a steady flow is strenuously opposed until the majority are convinced of the economy and efficiency of this method.

DUTY OF WATER. The amount of land which can be irrigated with a given quantity of water, or the relation which these bear to each other, is commonly expressed by the term duty of water, as noted on page 195. The investigation of this relation is one offering peculiar difficulties, as there discussed. Many studies have been made and the results embodied in various scientific reports and semi-popular works on the subject.[1]

These reports show in general that more water is used than is necessary for the production of the best crops and that when greater economy can be attained the area of irrigated land can be increased. This is demonstrated by the results obtained when dependence is placed upon pumped water, as indicated on page 221. In Wyoming, and in several other states, the required rate of delivery fixed by law is 1 second-foot to 70 acres; in Idaho 50, in Oregon 80, in Nevada 100 acres, but in Colorado and some other states the determination of area is left to the courts. For convenience in connection with new projects the assumption of 1 second-foot to 100 acres is generally made.

The duty of the water is said to be low when only a small area of land is irrigated by a considerable stream, for example, if 1 cubic foot per second is used on 70 acres. It is high if this quantity irrigates 160 acres or more. When we consider water not as flowing in a stream, but as held in a reservoir, we speak of low duty of water in that 3 acre-feet of water has been applied during an irrigation season to a single acre, or in other words an acre has received an aggregate depth of 3 feet. The duty was high if the acre was satisfactorily irrigated by the

[1] Harding, S. T., "Operation and Maintenance of Irrigation Systems," McGraw-Hill Co., New York, 1917, 271 pages, illustrated.

Newell, F. H., "Irrigation in the United States," T. Y. Crowell & Co., New York, 1906, 433 pages, illustrated.

Newell, F. H., "Irrigation Management," Appleton & Co., New York, 306 pages, illustrated.

Teele, R. P., "Irrigation in the United States," D. Appleton & Co., 1915, 253 pages, illustrated.

Widtsoe, John A., "Principles of Irrigation Practice," Macmillan Co., 1915, 496 pages, illustrated.

Plate XV. A.
Cement flume, Tieton Canal, Washington.

Plate XV. B.
Casting portions of reinforced concrete cement flume, Tieton Canal, Washington.

Plate XV. C.
Siphon conveying waters of Interstate Canal under Rawhide Creek, North Platte Project, Nebraska.

Plate XV. D.
Cylindrical gates in Franklin Canal, El Paso, Texas.

application of a quantity of water which would have amounted to 1.5 feet in depth or 1½ acre-feet.

The theoretical duty of water is far higher than that actually obtained. There is need for the production of a pound of dry matter, for forage or other crops, from 300 to 1,000 pounds of water, as noted on page 75. This would mean a few inches in depth over the entire surface. To bring these few inches to the plant, however, requires the use of several times this amount of water in transporting the necessary quantity, because of the loss in transit by seepage into the soil, by evaporation and in other ways. Farmers have applied as high as 5, 6, or even 10 feet in depth on sandy soils and yet have complained of not having enough. Others assert that they have raised good crops on an aggregate of one foot of water in depth during the crop season.

The old rough-and-ready rule was an inch to the acre, meaning a miner's inch, or the fortieth or fiftieth part of a cubic foot per second. Later an inch to two acres became the more common expression, meaning that a cubic foot per second or 40 or 50 miner's inches, flowing through the irrigation season of, say, 4 months or 120 days, would irrigate 80 to 100 acres, giving an aggregate depth of 2.4 to 3 feet.

Products. The products obtained by the use of stored and other waters procured for irrigation are dependent largely upon climatic conditions. In a country of modern temperature and where there is almost continual daily sunshine, as in the arid region, the applying of water at the right time enables the farmer to control crop production to a large degree. In the warmer regions, as in Arizona and parts of California, crop follows crop in rapid succession.

The most valuable is the fruit crop, but the area devoted to fruit is relatively small. Of greater importance is the hay and forage crop, consisting principally of alfalfa, Pls. II. B, XIII. D, XVI. B. In the northern part of the arid region this can be cut two or three times a year and in the southern part five or six or oftener. It not only is a valuable forage plant, but enriches the ground through the peculiar action of the nitrifying organism on its roots.

Alfalfa forms nearly half of the irrigated crop acreage and

yields over a third of the crop value. Once established, or a good "stand" secured, it continues for several years to furnish annual yields without reseeding. Its roots, penetrating deeply, open up the hard soil, and if turned under it affords one of the best fertilizers for the succeeding crops. The alfalfa hay is preferred for most of the farm animals.[1]

The matter of most concern to the farmer is not so much his ability to raise alfalfa, by the use of water provided by storage or other means, but rather his chief problem lies in successfully disposing of the alfalfa at a price such as will yield him a proper return for his labor. When the country was relatively new and unsettled, and when there was a demand for forage far exceeding the supply, such a question did not arise, but the moment that development had proceeded to a point where the alfalfa must seek an outside market, then the price in each locality fell so low as often to be below the cost of production.

Under the first-named condition, the amount received and demanded for alfalfa per ton was the purchase price in outside markets plus the freight or cost of bringing the alfalfa into the place where needed by the cattle owners or contractors on the new work. When the settlers reached such a degree of success that they produced more than enough hay to supply the local demand, then the cost of freight was subtracted instead of being added to the price in the outside market. For instance, if alfalfa could be purchased for $10 per ton at Salt Lake City and the freight rates to a new project such as that at Minidoka, Ida., were $4 per ton, then the contractors on the Minidoka Project were compelled to pay $14 per ton. As soon as the local alfalfa fields produced a quantity in excess of the amount needed by the contractors and some of the alfalfa must of necessity be shipped to Salt Lake City for disposal, then the local price was that prevailing in Salt Lake City, or $10, less the freight charge of $4 per ton, netting the farmer only $6 per ton or even less if freight facilities were not available.

This simple fact was not early appreciated and hence arose great disappointment to the settlers who had founded their

[1] Beadle, J. B., "Progress of Reclamation on Arid Lands in the Western United States," Smithsonian Report, 1915, pp. 467-488.

hopes on the continuance of high prices due to pioneer conditions. They at once began to look for a remedy and with the assistance of employees of the Reclamation Service and of the Department of Agriculture, studied the practicability of reducing the shipping charges, notably by condensing the alfalfa into more easily transportable forms or, as it has been stated, "packing the hay into the skin of a hog," or of converting it into butter.

A considerable amount of capital and much time is required to secure good dairy cows or to get cattle or sheep to feed. In the hog business, however, a farmer can get well started in two years and with a small investment. It is stated that horses and cattle increase annually 60 to 80 per cent, sheep a little more than 100 per cent, while hogs should increase 600 per cent. Moreover, it takes less feed to produce a pound of pork than any other kind of meat produced on the farm. Experiments have been made on various reclamation projects, showing in one case, considered fairly typical, that in two years' experience with alfalfa pasture, an average annual return of over $45 per acre was secured. With the addition of a little corn, these returns were increased to from $70 to over twice as much per acre. Other experiments show that in the yield of certain pastured plats the hay consumed was sold in the form of pork at a value of over $25 per ton.[1] These matters, although apparently outside the field of investigation by the engineer, are of prime importance in preparing plans and in weighing the economics of various projects of water control and development.

The cereals—principally wheat, oats, rye, and barley—raised under irrigation come far below the forage crops; and next to these in order are vegetables, orchard fruits (Pl. XIV. D), and small fruit. In California the orchard fruits surpass the forage crops in value. The large production of hay and forage under irrigation illustrates the fact that in these states irrigation is, to a large extent, an adjunct of stock raising. The production of cereals under irrigation is relatively small.

[1] Holden, James A., "Experience in the Disposal of Irrigated Crops Through the Use of Hogs," United States Department of Agriculture, Bulletin 488, February 26, 1917.

The total value of all the cereals produced under irrigation in the United States is less than that of those produced in almost any one of the humid states of the East. In many localities the irrigation of cereals and staple crops has been brought about by local conditions, such as difficulty of transportation and consequent heavy cost of importation. The irrigated cereals in such localities are raised almost wholly for local consumption, and do not enter the markets of the world. Corn is now raised with considerable success under irrigation. The failures which first occurred on account of carelessness and the unintelligent use of water and from attempting to grow varieties not adapted to the locality are being corrected as knowledge is gained from experience.

For many years it has been the current popular belief that the crops produced by the irrigators far exceed in value per acre those produced by the dry farmer. Theoretically this should be a fact because with proper water conservation by storage it is possible to regulate the supply of moisture and with ample sunlight to bring about ideal conditions. Many individual examples can be cited of wonderful results. Taking such instances there seems to be no question but that irrigation must win in any comparison. There have been, until recently, no reliable figures sustaining the assumptions made, and it was not until the Reclamation Service began to obtain crop statistics that it was realized that the average crop production under irrigation was far less than usually believed.

The annual estimates prepared by the Reclamation Service show a steady decline during several years in succession of the average value per acre cropped. This is presumably due to the fact that each year more complete figures were obtained. In 1916, however, for the first time the average showed a gain over the preceding years, and while from about 1909 until 1915 the returns per acre seemed to decrease, the later figures have showed a gain. This may be explained in part by the fact that the early figures related largely to lands including old developed areas in the Salt River, Arizona, Uncompahgre Valley, Colorado, and similar projects. Each year a larger and larger acreage of raw land was added, tending to step down the returns.

These raw lands, after a few years in cultivation, have now become highly productive.

Alkali and Drainage. Where water is scarce and must be handled carefully, efforts are made to secure economy, but when a large supply has been made available by storage, the farmer is inclined to use it lavishly. Upwards of 15 per cent, or even more, of the irrigated lands formerly cultivated, have been injured by an excess of water. This has not only converted these lands into swamps but has brought to the surface a crust of earthly salts of various compositions included under the term of alkali, as shown in Pl. XVI. C.

The most effective way of removing alkali is to hold the ground water well below the surface by means of deep drains and thus permit excess soil waters to move downward. The water in descending in the soil dissolves the salt on and near the surface and a portion of it is carried off in solution in the drainage water. Deep drains, especially where they cut porous strata, are effective in lowering the ground water and removing alkali at long distances from them. On many of the United States Reclamation Service projects deep drains at average intervals of from one-fourth to one-half mile apart have been found effective. Investigations indicate that troubles caused by alkali yield to careful treatment, and even badly alkaline land, when properly drained and then irrigated, can be made suitable for cultivation. Large areas of alkali land in the West may be reclaimed at a cost below the actual increase in the value of the land. It is believed that the time will soon come when drainage will be as common in the irrigated districts as are the tile-drained fields of the Middle West.

All irrigation works must be accompanied by the building of adequate wasteways and drains. Throughout a great part of the United States, outside of as well as within the arid region, are thousands of acres of land which are either partly submerged, especially during the flood season, or contain an amount of water so large as to render their cultivation impracticable. Drainage must be provided for these lands, not only to remove the surface water, but to decrease the percentage of water in the soil itself. There are thus necessary two distinct but closely

related kinds of construction. First, the surface drains or wasteways, and second, subsurface or deep covered drains.

Surface ditches form by far the greater part of all drainage works. They are usually broad, shallow depressions designed to carry away as quickly as possible the excess of rain or flood water and to discharge this into the natural streams. By relieving the surface of this burden, it is often possible for the soil to quickly dry out and reach a tillable condition. In the case of some soils, it is necessary to provide deeper outlets which will actually draw down the water in the ground and permit the air to enter the interstices. In other words, the drains must be put down sufficiently deep to permit the escape of water from the upper 6 or 8 feet. What is desired is to reduce the percentage of saturation down to, say, 12 or 15 per cent.

The building of irrigation works should be accompanied by the construction of drains in the same way that the building of a city waterworks is accompanied by a sewage system. It is not always practicable to anticipate just where the drains will be needed. Some of the soils, apparently tight, will be found to transmit water freely, and others, which on examination appear to be porous, may be found to retain the water. It thus results that after irrigation works are built the seepage waters appear in unexpected places; the drainage system must be laid out in accordance with observations made as to the behavior of the underground water.

The main drainage, open ditches, located usually in the natural depressions, are built with gently sloping sides. The farm drains leading to these may consist of tile buried in the ground to a depth sufficient to keep the water table well beneath the surface. The construction of these drains through the wet lands necessitates the use of machinery so arranged that it can be operated in water-soaked soils. The most successful is some form of drag-line excavator, such as that shown in Pl. I.C, which operates a bucket on the end of a line in such a way as to take out the material whether wet or dry.

In many places drainage works are employed as an adjunct to the irrigation canal. On benchlands or gently sloping hill-

sides the water which escapes from one man's farm is caught by the lower laterals and used by his neighbors below, and there is none left to stagnate, the surplus from the upper cultivated lands being of value in watering the lower meadows. There are cases, however, where the question of disposing of the water is as important as that of obtaining it. These are on the nearly level lands, where the subsoil has been filled to saturation by the water which has no opportunity to escape, and where expensive works are required in order to redeem the lower lands for agricultural purposes.

There is probably no one engineering operation that seems more simple than that of location of drains. Looking at the surface of the ground, the ordinary observer will infer that the drains should follow certain depressions. Acting under such impulses, thousands of dollars have been wasted in building drains which when constructed were found not to remove the excess water as anticipated. The reason is that the underground conditions are not usually revealed by the contour of the surface and that the movement of the water through the soil is controlled by conditions which are not at once apparent. These may be determined by a carefully planned series of test pits or bore holes, so located as to ascertain the character of the subsoil and slope of the water table.

As an example may be noted the Shoshone Project in Wyoming, in which the soil, of 4 to 6 feet in thickness, is underlaid by gravel. The general surface has a fall of about 20 feet to the mile. Apparently there could be no danger of swamping such an area as water would flow down the surface or into the gravels. It was assumed that the gravel could deliver any excess water to the deeply cut natural drainage lines. As a matter of fact, however, swamps did develop on these relatively steep slopes and drains built according to surface indications did not relieve the situation. Carefully conducted investigations showed that there were certain bands of gravel less pervious than others and that only when the drains were so located that these bands were cut could the accumulated water be discharged through the barrier and the swampy conditions relieved. It was by thorough research that these unexpected conditions were found to exist in

material which ordinarily is supposed to be readily traversed by water.

Before undertaking any considerable drainage enterprise, a map should be prepared showing not only the surface conditions, but also the depth to hardpan or to the water table and other facts such as may be ascertained by field examinations of the area. On the basis of this information, it is possible to prepare plans which may enable large economies, as against the frequently haphazard system of simply digging the drains and then trying out their efficiency. The distance between drains, their size, slope, and other conditions, must be worked out in accordance with the full information obtained by field examinations and by the analogies presented by successful work elsewhere.

The development of drainage is proceeding rapidly as larger experience has been obtained and more complete information is had concerning the essential details. Well-planned investigations are needed, however, into many of the details of the movement of water underground through the influence of gravity, capillarity, and other forces, as modified by soil texture and composition.

Plate XVI. A.
Measuring water to farm laterals. Uncompahgre Project, Colorado.

Plate XVI. B.
Stacking alfalfa hay, Garden City Project, Kansas.

Plate XVI. C.
Alfalfa field injured by alkali due to excessive irrigation, Shoshone Project, Wyoming.

Plate XVI. D.
Apple orchard, North Yakima, Washington.

CHAPTER XV

TRANSPORTATION OF WASTE THE THIRD USE OF WATER

The assertion that the use of water, in the disposal of sewage, and of industrial wastes in general, is next in importance to food production, comes as a shock to most persons who have not carefully thought about these matters. The employment of watercourses in this connection is more often regarded as an abuse than as a use, and the natural impulse is to denounce the pollution of streams as an outrage on the public. In a rapidly developing country where population is increasing and industries are multiplying, there human and industrial wastes quickly accumulate to a point where health and life itself are threatened. Even in primitive times or among Indian tribes, village sites or even small towns were abandoned because of the nuisance or infection bred from such accumulations. Under such conditions either the rivers must be used to wash away the polluting substances or drastic action taken to limit industry and settlement.

In most industrial operations and in nearly all sanitary appliances, water in large quantities is used. It is taken out of the general circulatory system, employed for a short period, and then returned, carrying with it the substances for which we have no further need and concerning which our chief anxiety is to get them out of sight and smell as quickly as possible, even though they may contain fertilizing material or substance from which valuable by-products may be derived.

Thus, in the present stage of development of civilization and of population, water has become the principal agency for carrying away the things we no longer require. Whether we like it or not, we must recognize this condition and the fact that in

innumerable processes water is and will be employed in larger and larger volumes for washing away the things we do not want and which if not disposed of become nuisances.

Our immediate concern is not so much that of preventing the use of water as of determining the extent to which, when once thus used, it can or should be returned to the natural stream channels. It is whether we should permit the foul water as it escapes from sewers or manufacturing establishments to go directly into the brooks and creeks or whether, before being thus turned loose, it can or should be deprived of its load of deleterious matter. In short, because of the long-continued and tacit recognition of an existing custom sanctioned by law and habit, the present questions are not those of prohibition of use but of regulation of an abuse. The right of use must be clearly defined and the limits of abuse equally well set.

These limits to which human and industrial wastes may be discharged into a stream are by no means uniform nor susceptible of accurate definition. It is necessary in each case to consider the surrounding conditions, to make careful investigations, conduct researches and balance the benefits as far as possible against the injuries caused; the persons or communities suffering injury to be recompensed by those who are benefited.

It is easy to imagine localities where unrestricted dumping of waste is of no consequence, simply because the amount thus deposited is infinitesimal compared to the vast volume and naturally foul condition of river water. For example, one or two small factories or settlements along the muddy Missouri cannot produce any injury possible of detection. On the other extreme, the small creeks formerly filled with clear, mountain water may be quickly defiled by the waste from a crowded manufacturing town and become a menace to the people living below.

The question then is as to whether the benefits to the community or to the public in general of the former pure water—perhaps unutilized—were greater than those now conferred by the manufacturing village. Do the net profits of the industry justify the destruction of natural values? If so, should these profits be used in part in repairing or in preventing injury? It is easily conceivable that in most, if not all, instances, the abuse

of water may be prevented at a cost which is less than the advantage which results from neglect. The answer to these questions can be had only after impartial study of the facts and careful weighing of the evidence.

The balancing of benefits and injury is often complicated by conditions which cannot be readily taken into account. These are the intangible vested rights or traditional attitude of the people or communities where use and abuses have grown up slowly side by side and the public has become accustomed to these. When people in general cannot imagine any other conditions than those which exist, there is little possibility of arousing sufficient interest to check an abuse. For instance, a small mill which develops gradually into a large manufacturing establishment begins at first to discharge its refuse into the stream, and without any perceptible injury. As it grows, the houses of workmen are crowded in the vicinity, the processes of manufacture are gradually changed, and more and more noxious substances are thrown into or along the stream, already partly polluted. At no time is there a conspicuous change from conditions which have existed a few months before. Nor is there an inciting cause for anyone to make effective complaint until the conditions become intolerable, forcing the public to appreciate that new and unbearable conditions have developed.

In the meantime, certain vested rights have attached, sustaining the contention that stream pollution is in the natural order of events: the persons injured have slept on their rights or by acquiescence have allowed them to diminish to a point where it is easy for the manufacturer to demonstrate that his profits and the gain to the community far exceed the dubious loss to others.

There is no doubt but that there are localities and conditions where the transporting of waste products has attained sufficient importance to justify large expenditures by the public along the line of water conservation, especially when undertaken in connection with other uses of the water. For example, in preparing estimates of the cost of production of power or of water storage for municipal and other purposes, there may be recognized among the benefits to be derived from such expenditure the disposal of sewage. Because of such gain, additional outlay

may be justified or a plan approved which otherwise might seem inexpedient.

This is notably the case where, with rapidly increasing density of population, the question of domestic and city water is becoming a more and more intricate problem. Each settlement along a river from the time of the building of its first house, usually has derived its necessary water supply from the stream and, as the number of houses increased, sewers have been built emptying below town. The diluted sewage has continued to flow down to the next settlement below and there been used until after a lapse of some years the water has become obnoxious or the death rate increased.

Little thought is usually given to these conditions until they result in an epidemic—with large loss of life. Customary inconveniences or slowly increasing death rate do not arouse people to action. The first impulse which follows the recognition of the bad condition is to go to the other extreme, to demand that all sewage be excluded from the streams. This is practically impossible, as the water which is used by municipalities or employed in manufacturing establishments must sooner or later return to the natural drainage channels. Before being returned, however, it is possible to bring the water back to a fair degree of purity. The cost of so doing is the governing factor.

The improvement of the condition of the water which has once been used is largely a matter of dilution.[1] After the visible impurities have been disposed of and the bacteriological contents reduced as far as practicable, the next question is to secure as great a degree of dilution as possible. To do this there must be available during the dry seasons an adequate amount of water and while under ordinary conditions it would not pay to store water simply for dilution of waste, yet in connection with power development or other purpose this may be brought about and enable the solution of a difficult problem.

Water is the universal carrier and solvent, and of necessity must be largely employed in removing many noxious materials.

[1] But not in Miles and activated sludge processes; aeration is necessary in the Miles process; activated sludge sewage will support fish at end of treatment. These treatments usually require concentration.

During the process of transportation of organic matter in open stream channels there is usually set up more or less chemical and biological action which tends to eliminate the harmful organisms. If the foul water is well diluted and is exposed to sunlight and to air in its course downstream, there is a gradual return to normal conditions.

While it may be impracticable to preserve the streams of the country in their original purity, yet research indicates that it is possible to so act that they may continue to perform varied and useful functions, bringing needed water to many communities and taking away the waste material, provided that in so doing they are not overloaded. The proper adjustment is a matter which must be considered in each case. It demands the skill of the engineer in planning and devising works of conservation to furnish a regular supply and the experience of the sanitary and biological experts to see to it that the highest practicable degree of purity is attained in anything discharged into the watercourses. Filtration of waters before use and again after use and before release into the natural channels, together with a steady flow in the latter—sufficient to secure full dilution—is to be sought.[1]

Relative Values.[2] The gain to individuals or to corporations through the relatively easy way of disposing of sewage and waste by discharging it into rivers has been accompanied by losses to communities or injury to the public welfare. The effects of the structures, such as dams across the rivers, the

[1] Hansen, Paul, "Control of Stream Pollution," Illinois Academy of Science, 1913.

Hoad, W. C., "The Michigan Water and Sewage Law and the Grand Rapids Stream Pollution Decision," Engineering Bulletin No. 4, Michigan State Board of Health.

Leighton, Marshall O., "Pollution of Illinois and Mississippi River by Chicago Sewage," U. S. G. S. Water Supply Paper No. 194, 1907.

Legg, F. G., "The Work of the International Joint Commission on the Pollution of Boundary Waters," Michigan Engineering Society Proceedings, 1915, p. 79.

[2] The remainder of the chapter is a slight modification of a manuscript by Victor E. Shelford, biologist in charge of Research Laboratories, Illinois Natural History Survey, and assistant professor of Zoölogy, University of Illinois.

drainage of extensive marshes and the sewage discharged into the streams have disturbed the delicate adjustment of life conditions of plants or animals. The actions and reactions are usually complex and the ultimate net balance of benefit or injury may not be apparent until after careful research.

People in general are apt to see only those things which are brought prominently to their attention, disregarding other matters as of little or no significance; thus the natural resources which have been lost or diminished in value to secure an immediate gain are usually not given great weight. To illustrate the contrasting attitude of those who view the same question from different standpoints, the following instances may be given. A manufacturer, when confronted by law which will ultimately compel his factory to stop polluting a stream, exclaims:

"What! Would you destroy our great industries because of a few fish, for the sake of the cattle of a few farmers or the health of a few people? If people want fish, let them go to sea or somewhere else and get them. If they don't like the foul water, let them move to a greater distance from the factory where the water is better. If they and their cattle can't drink the water, let them drill wells for themselves."[1]

On the other hand is the attitude of the extreme conservationist who denounces public indifference in the disposal of sewage, and says: "There is little blacker or more nearly criminal in the history of the country or an exhibition of greater disregard for the rights and health of the people than the pollution of the streams by manufacturing and other industrial interests. It is harder to repair the damage they have done, than all the acts of careless fishermen. To those who know the facts, have seen the dire results, and have the work of rehabilitation in hand, the faults of Judas Iscariot and of Benedict Arnold are more to be condoned and of less harm to the people than the ruin of the fisheries and the water supply for domestic purposes."[1]

[1] Meehan, W. E., "The Battle for the Fishes," *Canadian Fisherman*, 1917, 4: 275-279.

In the words of an aquatic culture advocate: "A fish cultural experiment station is what is now urgently needed; an institution equipped for water culture, and charged with the duty of carrying out a well-planned line of experiments, bearing on its economic problems. This is needed to supplement the hatcheries and to bring their work to fruition."[1] On the contrary, we have from a cannery operator: "This nonsense about fish culture makes me tired. What I want to know is how to make every dollar invested in fisheries pay a dollar and ten cents. When we have canned the last salmon we will can something else."

The conservationist says of Niagara, "The falls in their full glory belong solely to the nation and to posterity." While the engineers respond, "It's a shame to let all that power go to waste."

Who is right? To a certain extent each is—but in each case the special interest fails to recognize the rights and interests of the other side in making his own calculations. The present unsatisfactory condition of our aquatic resources is largely due to the intolerant advocacy of this or that, of "pork," profits, industrial expansion, sport, or economy carried to penuriousness. Modern legislation for the protection of fishes has often been less effective than that of 300 years ago. Proposals for its complete reorganization have scarcely gotten a hearing.

In 1606 an act passed by James VI of Scotland forbade the pollution of lochs and running streams because it was "hurtful to all fishes bred therein."[2] The punishments for violations were severe. Later by 312 years we are just confronted with a problem of substituting fish for beef, pork, and mutton and find our laws no better. With the development of modern industries and sewerage systems the bathing and recreation grounds have been destroyed and fisheries greatly injured or destroyed. Some fisheries had been depleted already as a result of the use of "improved" catching devices and the absence of protective measures such as existed in some places eight hundred years ago.

[1] Needham, J. G., and Lloyd, J. T., "Life of Inland Waters," Ithaca, 1916.

[2] Day, F., "British and Irish Salmonids," London, 1887.

In Scotland, about the year 1220, it was ordained that from Saturday night to Monday morning it should be obligatory to leave a free passage for salmon in all the various rivers.[1] Almost seven hundred years later a similar law was enacted in certain of our Pacific states, but the time is shorter, being from Saturday night to Sunday night. The absence of such laws in New England a century ago has caused infinite damage to the salmon and shad industries.

Fisheries. The destruction of fisheries by using the streams to transport waste is the first and most obvious injury, but they make up only a small part of the losses. There are other more important aquatic, biological values as noted on page 274. It has been argued that the fisheries of one of the most productive rivers are not worth as much as the products of the smallest industry which is throwing wastes into the upper course of this river. This argument carries much weight; it is, however, faulty. First of all, economists have been predicting a shortage of food; furthermore the values used are the values to the fishermen, not to the public. The Alaska salmon canning industry, taking only the salmon canned, shows[2] that about one-third of the employees and one-third of the capital are devoted to fishing, while the value of the fish to the fishermen is about one-third of the value of the canned product to the canneries. Salmon fishing is more expensive than many other types. Fish should be compared with raw materials and not with the products of factories on which much labor has been expended. Our food supply should be increased, not decreased to bring profit to a few owners of manufacturing industries.

Recreational Values. Besides the biological values, there are the recreation and æsthetic values. They must be considered in any attempt to balance the gains and losses. There are two types of recreation which have to be taken into account. One is the camping, shooting, and fishing, another the wading, rowing, and afternoon and Sunday outings for children and

[1] Day, F., "British and Irish Salmonids," London, 1887.

[2] Evermann, B. W., "Alaska Fisheries and Fur Industry in 1913," 1913 Report of the Commissioner of Fisheries, app. II: 1-139.

those who must take advantage of things near at hand. These two uses of waters and water margins overlap only to a small degree. The value of a stream and its margins for its sportsmen can be ascertained through suitable investigation. For example, the Fox River[1] in Illinois is about 100 miles long and its valley contains a population of 234,000. The banks are dotted with cottages and there are some clubhouses. It was estimated that there are over 6,000 boats of all kinds on the river. The capital invested in these cottages, clubhouses, and boats is the capitalization; the interest on this, the salaries of caretakers and the value to local merchants is the annual recreation value, but what it is has never been determined. Such activities tend to disappear from badly polluted streams.

For the general welfare of its citizens every large city provides parks with lagoons for rowing, bathing beaches, swimming pools, and in some cases forest preserves on the outskirts. Chicago[2] is a good city from which to make estimates, for it has all these things within its limits or under its immediate influence, further the Fox River is valuable for comparison with the upper Illinois and Des Plaines rivers because of the nearness of both to the city. Chicago's park properties cost over $56,000,000. The interest on this sum and cost of maintenance amounts to nearly $2.60 per capita annually exclusive of lighting. The forest preserves[3] will probably cost nearly twenty million when completed and this will add another dollar to the annual per capita outlay. This city also spends seven cents per capita for outdoor bathing facilities. The parks contain lagoons which provide rowing and a limited amount of angling. They correspond quite closely to the conditions afforded by a river and its immediate margins for people living close at hand.

Chicago Sewage. Chicago "treats" its sewage by dilution with water drawn from Lake Michigan and adjacent waterways

[1] McCurdy, G. E., "Report of Survey and Proposed Improvement of the Fox River," State of Illinois Rivers and Lakes Commission, 195.

[2] United States Bureau of Census, General statistics of cities, 1915.

[3] Reinberg, P., and others, "The Forest Preserves of Cook County," Chicago, 1918.

through the South branch of the Chicago River and a canal which receives other streams and finally ends in the Des Plaines River, which is one of the upper courses of the Illinois. There are strong evidences of pollution more than a hundred miles below Chicago. Fishes have been wiped out, and sportsmen's activities reduced to a minimum. About 250,000 people living in this part of the valley and area immediately adjacent are affected by the conditions which the sewage produces in the river. It is not possible to put a value on the loss they sustain. "For over a hundred miles from Chicago, the inhabitants of the valley seem to have relinquished the most valuable rights of riparian owners. The water is not fit to drink, nor wash in, nor to water stock in, nor for any other domestic and industrial uses of a normal river. Fish die in it; the thought of swimming in it is repugnant to the senses; boating far from being a pleasant and healthful diversion can be enjoyed only by the hardy. The stream flows with the majestic sweep of all great rivers and the banks are overhung with rich luxuriant foliage; but the water is discolored, malodorous, poisonous. Fine black organic sewage mud covers the bottom and deposits on the shores when the river overflows its banks."[1] From the loss of nearly all use of the river for recreation, angling, swimming, camping, taking merely the $2.60 Chicago spends annually at the present time, exclusive of the forest preserves as a basis, we find that the 250,000 people of the valley may lose $650,000 per year on this score alone. It may, of course, be argued that they would not use the river if it were clean, that tributaries supply necessary recreation grounds, that half of the people live in towns which supply these things in parks, that they would pollute the river themselves. Further, one might find that they are quite resigned to conditions because they "cannot be remedied"—a sophistry of those who wish to continue the present system. Only careful investigation can determine what their loss is. However, there are æsthetic and moral values to be considered. Furthermore, the annual loss to the inhabitants due to the lack of visiting

[1] Soper, G. A., Watson, J. D., and Martin, A. J., "A Report on the Disposal of Sewage and Protection of Water Supply of Chicago, Illinois," The Chicago Real Estate Board, 1915.

sportsmen, noted above for the Fox River, and the loss due to hindrance of the general development of the valley because of all the disadvantages and the nuisances which the sewage causes, the destruction of cattle water, dangers to public health, all have to be taken into account. The loss of fish lies chiefly in angling losses at present, but the sewage is rapidly encroaching on commercial fisheries further down. In addition there is a loss of an almost annual crop of ice, or ice which is dangerous to public health is harvested.

This situation can be relieved by treatment of Chicago sewage. A recovery and treatment plant has been estimated[1] to cost Chicago $3,800,000 for 50 million gallons of sewage or $38,000,000 to care for the city's entire discharge counted at 500,000,000 gallons per day at a cost of over $8,000,000 for annual running expenses with recovered products worth upwards of $3,000,000, leaving more than $5,000,000 annual expenses. These figures based on packing-town sewage are perhaps larger than for an average.

According to figures by Winslow and Mohlman,[2] who worked on New Haven sewage, the cost for Chicago on the basis of the average of their two stations when treated by the Miles process, would be $3,300,000 for a year without recovery products or about $1,500,000 with sale of recovery products deducted. The figures of Weston show an actual profit for his samples of Boston sewage. In other words, if Chicago spent as much on cleaning up its back yard as it does on beautifying its front yard, it would not be making a sewer out of a once beautiful valley. The estimated economies in government under a plan proposed by the Cities' Efficiency and Economy Commission would almost build a fifty-million-gallon plant every year, and the operating expenses would increase taxation about 6 per cent.

[1] Wisner, G. M., "Report on Sewage Disposal," The Chicago Sanitary District, Chicago, 1911.

Hill, C. D., "The Sewage Disposal Problem in Chicago," *Am. Jour. Pub. Health*, 8: 833-837, 1918.

Pearse, L., "Activated Sludge and Treatment of Packing-Town Wastes," *Am. Jour. Pub. Health*, 8: 47-55, 1918.

[2] Winslow, C.-E. A., and Mohlman, F. W., "Acid Treatment of Sewage," *Municipal Journal*, 45: 280-282; 297-299; 321-322, 1918.

Counting all losses, the per capita loss to the people of the valley would greatly exceed the per capita expense to Chicago. The total annual losses to the valley may readily equal Chicago's total expense for treatment.

Does It Pay? The figures of cost of sewage treatment show great variation and it is probable that any estimate of cost or recovery are wide of the mark in one direction or the other. However, if one brought all the values together after careful investigation, he could probably prove, with the moral, educational, and recreational values taken into account, that it does not pay to pollute streams or other bodies of water with untreated sewage and industrial wastes or to modify streams and swamps without careful consideration of values other than the industrial and commercial. Such investigation and proof are not necessary. The nation has provided immense national parks and forest reserves for the use of everybody, but far away from the bulk of the population. Each state should provide its citizens with some of the same kind of recreation grounds, should protect each and every small community from the destruction of its recreation grounds. Each child has a right to wade in the creek near his home and pick up stones; his own community must protect him from disease and filth.

Under pressure for economy some engineers have been slow to recognize the rights of the smaller community to the fisheries, sporting, and æsthetics of its watercourses against the interests and selfish encroachment of the larger. Certain American engineers[1] said of the Royal Commission on River Pollution: "The main interest lies however in the complete failure to recognize dilution of sewage as method of treatment. Its dilution in water was regarded exclusively as a method of disposal. A city which has a neighboring body of water, where it can be practiced safely, possesses an important natural resource." The men failed to see the beauties of such a theory as exemplified by most of our streams where such treatment is practiced, as a notable example the Chicago drainage canal.

The capacity of streams to carry away human and industrial

[1] Metcalf, L., and Eddy, P. E., "American Sewerage Practice," Vol. III, "Disposal of Sewage," New York, 1916.

wastes is a natural resource: the removal of these is necessary; but this capacity like other natural resources, if it be admitted to be such, being largely of a biological nature (self-purification being a biological process), is quickly destroyed by overtaxation. Such treatment can be successfully practiced only under close supervision, as is necessary in scientific forestry, for example. The principle set down by the Massachusetts state board of health in 1875 still holds, "that each community should dispose of its own filth without allowing it to become a source of offence to others.

"While realizing that in certain cases the discharge of crude sewage into boundary waters may be without danger it is our judgment that effective sanitary administration requires that no untreated sewage from cities or towns shall be discharged into boundary waters." (Report of engineers to the International Joint Commission.)

Apparently the boundary waters are not a natural resource for the treatment of sewage by dilution, and why not? Because every country protects its humblest citizen from the acts of foreign nations by going to war, if necessary, for the lives of only a few. Most often engineers regard waters only as a source of supply for communities which have waterworks, but Phelps recently said:[1]

"The only proper basis for a policy of stream protection is the principle of conservation of stream resources, or the maximum beneficial use of the stream. The application of this policy involves the study of all the various uses of the stream and of the value of each. From a purely economic standpoint, if for no more potent reason, the protection of life and health demands first consideration, and that protective policy is best which best protects the public health and permits the maximum utilization of the other valuable properties of the stream."

The sanitary engineers for a state board of health recently said: "The principal evil growing out of the extensive installation of modern sewerage systems is the pollution of streams. Many streams in the United States have been grossly polluted

[1] Phelps, E. B., "The Control of Stream Pollution—A Problem in Economics," *Mun. and Co. Engineering*, 55: 22-24, 1918.

as to be fit for no other purpose than as a receptacle and an open drain for putrefying wastes. This situation is due entirely to the fact that the benefit from the installation of adequate treatment works accrues to the downstream neighbors of a community using the stream as a wasteway rather than to the community itself." The discussion coming from some of the worst offenders is not encouraging, as it usually contemplates the continuation of present conditions with some increased load added to the streams. Ten or twenty years hence they anticipate that it will be necessary to treat the sewage from enough of their population to keep conditions not too much worse than they are now.

The existence of such large and noxious wastes and the seriousness of their effects have perhaps been sufficiently enlarged upon in the preceding pages. The natural argument in condoning the fact "is that it constitutes an unfortunate but necessary and inevitable accompaniment of the development of manufacturing." But such a general argument as that is met when we consider for a moment the conditions that prevail in other countries. When the manufacturer makes such a statement, and he is asked if manufacturing is as general, if population is as dense, in this country as it is in England, or Belgium, or France, or Germany, taking conditions before the war, he will hardly venture to say that it is.

In none of our states have we reached the development of manufacturing, nor the density of population which exists in those countries; yet fishing in the streams of the Old World is better than it is in these streams in the manufacturing parts of the New World; and pollution at the present time is much greater here than it is there. Much improvement, as a matter of fact, has been made in the older parts of the world in the course of the last half century in cleaning up the streams, they have paid attention to that, whereas we have neglected the problem.[1]

In this country one goes to college and takes a course in the chemistry of paper making and seldom hears a word about how

[1] Ward, H. B., "The Elimination of Stream Pollution in New York State," Trans. Am. Fish Soc., XLVIII, 3-25, 1919.

to dispose of the wastes, not even in the university of a state in which paper mills have destroyed many salmon and their breeding grounds. The stream of our information in these matters is dried up at the source. The legal situation relative to streams pollution is peculiar. In most cases there are adequate laws to prevent the contamination of streams, but when the state goes into court with a complaint, the offender usually says, "Tell us how to dispose of our refuse without polluting the streams and we will be glad to do so." He usually is sustained by the court in continuing the nuisance until the complainant has shown how it can be done. In case of most misdemeanors the offender has to invent his own means of stopping the offence, but in these cases the state must discover it for him. Perhaps the state should do it in the future. The condition of our laws should be remedied after careful investigation.

Water Fertilization and Self-Purification. It is a fact that a certain amount of purely household sewage added to water increases nitrogen and hence acts as a fertilizer increasing food for fish and other aquatic animals. Certain European towns run their sewage into ponds where the yield of carp is increased through the increase of fish food. It is easy to argue that the addition of sewage to streams will do good! Of course that would settle it if there were not more facts to consider.

First, in practice there is no such thing as pure sewage; even in the smallest town, the garage runs oil and gasoline into the sewers and the creamery adds milk wastes or the gas plant adds quantities of deadly poison until there is really no certainty that the process of breaking down the organic matter of the household sewage present into nitrogen available for fish food will go on. In many cases it certainly does not.

Secondly, how much sewage can be used advantageously as fertilizer? The amount that can be used for carp may be known, but carp is not prized by Americans and amounts suitable for carp may be detrimental to most aquatic resources. It is difficult for one to conceive of the physiological diversity in the animals of a river.

Studies of fishes in the Illinois River at points where self-purification has proceeded far enough to permit fishes to live,

appear to show that fishes have increased. This case, however, is complicated by the fact that water diverted from Lake Michigan has increased the flow and added greatly to the overflowed areas and hence to the shallow water for feeding and breeding. This increased space is believed to be in part responsible for the increase in fish.

The number of fishes which come from the lakes and bayous which are little affected by the pollution is unknown, as well as the number of fishermen before and after the introduction of Chicago sewage and accordingly this case cannot be used to show anything about this. Further, the loss of the Buffalo fish, the big pickerel and wall-eyed pike noted on page 276 indicates that the increase has not been general, but that while it is not certain that some fishes are favored, it is more than probable that what favors one species is detrimental to another. There is no investigation showing how much sewage is advantageous.

When is a stream self-purified? The sanitary chemist and bacteriologist have criteria, but so far as their tests are concerned, the stream may be so thoroughly purified, by acid waste for example, that nothing belonging to our aquatic biological resources remains.

The most delicate test for the suitability of water for important aquatic organisms is perhaps the microscopic organisms which serve indirectly as food for fishes. When these are gone, especially from the bottom, there can hardly be any fish. The biologist with careful study, based on new research, can establish the point at which self-purification has taken place, for example, from the standpoint of fish. One finds in the literature assumptions about dissolved oxygen, but little that is established from the standpoint of the physiology and interdependence of important aquatic animals. The ecological requirements[1] of important aquatic species are the final court

[1] Shelford, V. E., "Ecological Succession. I. Stream Fishes and the Method of Physiographic Analysis," Biol. Bull., 21: 9-35. "II. Pond Fishes," Biol. Bull., 21: 127-151. "III. A Reconnaissance of its Causes in Ponds, with Particular Reference to Fish," Biol. Bull., 22: 1-38. "Suggestions as to Indices of the Suitability of Bodies of Water for Fishes," Trans. Am. Fisheries Soc., 44: 27-32.

of appeal, but the law on which decisions are to be based is yet to be constructed from existing scattered knowledge and especially from future research.

NEEDED RESEARCH. If it is possible to determine what injury has taken place, some one may ask what is the use of conducting elaborate experimental studies. This is because we must know what constituents of waste effluents are capable of doing damage.

The relations of fishes to the various effluents are too little known to warrant many conclusions. A large number of questions demand investigation. Tests of the toxicity of sewage and industrial wastes and other poisons introduced into the water must be made. In doing this it is not sufficient that we take any fish or other animal we pick up. An animal that is representatively sensitive must be chosen and after this has been done, it is necessary to consider that every life history may be represented as an endless chain made up of links of different strength, as noted on page 278.

Conditions in streams and other bodies of water vary; the concentration of the polluting substance should be known.[1] The minimum flow of a stream usually gives the greatest concentration. The summer low-water conditions are dangerous because of little flow and high temperature, which increases toxicity; the winter low water because of slow flow and ice, which prevents aeration. Perhaps something might be done, such as forcing air through the effluent near the point where the pollution is introduced, to reduce this danger during critical periods by increasing oxygen and removing carbon dioxide.

The removal of constituents and the results of treatment of various polluting substances must be fully analyzed. It is necessary to know the results of treatment of sewage, industrial wastes, etc., in terms of their effects on useful aquatic animals. If coal tar[2] wastes are partially recovered, it is neces-

[1] Shelford, V. E., "Ways and Means of Measuring the Dangers of Pollution to Fisheries," Bull. Ill. N. H. Surv., 13: (2) 25-41, 1918.
"Fortunes in Wastes and Fortunes in Fish," *Sci. Mo.*, August, 1919.

[2] Shelford, V. E., "An Experimental Study of the Effects of Gas Waste upon Fishes, with Especial Reference to Stream Pollution," Bull. Ill. State Lab. Nat. Hist., 11:381-412, 1917.

sary to know whether the residue is still toxic. Experiments have shown that nearly all constituents are, and hence any residue will be almost certain to be poisonous. The substances which are introduced into the water not only affect fishes directly but also act through effects on the bottoms on which eggs and valuable mollusks rest.

The covering of bottoms with a large amount of sawdust and other rubbish makes the spawning grounds useless. The reaction of the animals demands attention.

The time it takes a body of water to recover if it has once been depleted must be considered. It has been shown that a whole association of plants and animals must redevelop in places of this sort. If a pine forest is destroyed by fire, fireweeds grow up, followed by cottonwoods or birches and after a long time pines again. A similar slow process must take place in depleted waters.

There is danger in decisions made without investigation of a particular case. One important reason for this is that poisons are in some cases rendered much less toxic by salts in solution in the water polluted and in other cases they are rendered much more toxic by the salts present. The effect of greatly diluted effluents should be studied under culture conditions for one or more seasons. When the engineer and chemists have an effluent to test, there is no one to test it adequately and no one to tell them what its effects will be. Provisions for such investigation should be made at once, and on a larger scale than ever before.

Plate XVII. A.

Blackfeet Indians on their reservation in Montana employed on conservation works. In the foreground old Iron Eater, one of the best workingmen of the locality.

Plate XVII. B.

Apache Indian laborers at Roosevelt Reservoir in Arizona. The employment of these Indians was made possible by the construction of works for water conservation.

Plate XVII. C.

Mountain forests and lake made possible by the run-off from the forested area. It is necessary to protect the wooded area around such natural lakes in order to maintain good conditions of water supply and to prevent excessive erosion of the hill slopes such as follow the destruction of the natural growth.

Plate XVII. D.

Underground storage made available by deep boring; an artesian well near Roswell, New Mexico.

CHAPTER XVI

INDUSTRY AND TRANSPORTATION, FOURTH AND FIFTH USES OF WATER

MANUFACTURING. In the manufacturing industries, including the production of power for electrical transmission or for direct application, water conservation by storage has found and is finding a wide application. While large works have been built for municipal supply and for irrigation development, yet the number and diversity of structures built by commercial interests far exceed those provided for other purposes.

Before the question of city supply began to be seriously considered in the United States, there were built innumerable small dams for gristmills, sawmills or for ponding logs. Each year there was an increase in the number of these up to the time when steam power began to assert its place and crowd out the small water power mills. With the subsequent revival brought about by electrical transmission of power, attention was again drawn to the question of regulating the stream flow and of providing by storage adequate water to furnish power for the peak loads.

Water may be needed in manufacturing not only for power production but for direct consumption in one or another of the various processes or for use in steam boilers or simply for washing or cooling. Many industries require an ample supply of clean, clear water such as can be had only by holding it in ponds to permit the sediment to settle. Occasionally the normal flow of the stream is charged with a considerable amount of mineral matter in solution, while the flood waters are relatively free from dissolved mineral matter. In such cases water storage may be resorted to in order that the softer water may be had.

A combination of the interests of municipal and domestic

supply, of fish and of water fowl culture, of irrigation, of sewage disposal, and of the creation of power, may render practicable the building of storage works which for any single purpose would not be financially feasible. It is peculiarly the duty of the engineer to study such possibilities and while planning to conserve the water, at the same time consider how this water may be put to the largest practicable number of uses with consequent greatest gain to all concerned. For example, in the case of the Reclamation Service, while primarily its duty was to store water for irrigation of lands, yet the engineers in charge felt that they were obligated not merely to consider the uses of water for production of crops, but at the same time to obtain the maximum development of power compatible with this use and to assist in the creation of municipal supplies and the encouragement of manufacturing. Many projects are thus studied which from the purely agricultural standpoint might be questionable but which were of undoubted value when considered in connection with the other purposes to which the water could be put.

Water Power. In the employment of water in the production of power are required large volumes with steady flow and an adequate fall. This use is ordinarily compatible with its later employment for irrigation or in manufacturing, so that development of water power goes hand in hand with the upbuilding of other industries.

Since 1900 there has been a notable revival of interest in water power development. Engineers are being called upon to a greater extent than in the past to utilize the larger and more inaccessible streams of the country, particularly through the building of storage works. Similar conditions prevail throughout the world, and in localities such as in Norway and Sweden the waterfalls are now being developed and utilized by electrical transmission, the cheap power making possible the manufacture of certain chemicals, particularly the fixation of nitrogen from the air to form the basis of agricultural fertilizers.

The fact that operations of the kind above noted need not necessarily be continuous, as in the case of supplying power for lights or street railways, renders practicable many schemes.

For example, the proposed use of power which may be developed in connection with an irrigation project brings up the objection that the power is intermittent in character and cannot be employed to advantage in the usual manner. In the undeveloped arid region, irrigation must precede settlement, cultivation, and the building of railroad lines; thus there is presented the fact that there is no immediate demand for the power which is available at reasonable cost. The engineer is confronted with the problem as to what to do with any excess beyond that needed for immediate construction purposes or for summer pumping for irrigation or drainage. One of the large outlets suggested for the use of such excess power is the fixing of nitrogen from the air and the manufacture of fertilizers so greatly needed in the new country.

A power plant such as that built at Minidoka on Snake River in Idaho is put to its largest use in connection with irrigation only during three or four months of hot weather. The plant to be kept in the best condition for this time of maximum demand should be operated continuously. It is obviously impracticable to shut down, disband the operating force and, in the summer, get back the skilled men and run the machinery at high speed. How, then, can the skilled force be kept busy throughout the year? The solution, above indicated, of chemical industry which can be carried on throughout the year or at intervals between the irrigation seasons is one peculiarly attractive.

In the instance just mentioned, it has been found practicable to develop a winter load by selling the power at low rates to the small communities, not merely for lighting, which would require only a small fraction of the power, but for heating the houses, schools, and other buildings, and for domestic uses, including cooking. The comfort of the community has thus been greatly increased and it has been practicable to create a market in a pioneer agricultural area. There is moreover the demand for fertilizers and it is probable that in similar localities, with the development of experience along these lines, it will be practicable to bring about the manufacture of chemicals needed by the farmers or by local industries.

Thus it happens that in connection with the works built for

other purposes, it is occasionally found by the engineer that power may be developed, particularly below storage dams. There are also points near the head or along the line of the principal canals where water of necessity must descend to lower levels and where power may be had. As a rule, however, the best and largest use of the water for power, as above stated, is not consistent with its economical employment in irrigation.

For most purposes, such as in manufacturing or in electrical lighting, and in transportation, power must be practically continuous or at least available at regular intervals throughout the year. Irrigation water, on the other hand, should be applied only during a limited portion of the year and at other times the surplus water should be accumulated in reservoirs or the canals should be allowed to become dry. There are occasionally conditions where power during the irrigation season has particular value and may be used to advantage, either in supplementing the water supply obtained in other ways or used in pumping or draining lower lands.

There are also instances where storage reservoirs are built on streams, the total flow of which is not available for storage. For example, it may be necessary to pass through a reservoir a certain minimum flow for the satisfaction of vested rights farther down the stream. The building of the dam and the permanent maintenance of high-water level in the reservoir enables the creation of a steady power because of the fact, above stated, that a certain quantity of water must continually flow through or around the dam. Such is the case above noted on the Snake River in southern Idaho, where at Minidoka Dam a certain low-water supply must be permitted to continue downstream to supply prior claimants. Here water power has been developed and is being supplied throughout the year, irrespective of the demands for irrigation.

The financial success of any project of water conservation by storage may thus be dependent to a large degree upon the complete development of all of these possibilities of power and related commercial enterprises. Hence it is incumbent upon the engineer in planning a system of water storage to consider whether by any modifications it will not be possible to provide

for power development and use. In connection with construction also there are always questions of cheap power, and cases have arisen where the cost of construction has been greatly reduced by arranging the original plans in such a way as to build the power plants first and thus utilize these in connection with the later construction work. For example, in building the Roosevelt Dam in Arizona, the fuel cost was a large item. Many of the difficulties were solved by first building a power canal and temporary power plant, the canal being located around the upper edge of the proposed reservoir and the power plant immediately below the dam which was to be erected.

The development of the natural resources of the United States in water power has been greatly delayed by lack of suitable laws drawn to encourage or permit investment of private or public fund and to protect the interests of all concerned.[1] Congress after Congress has failed to agree upon a measure acceptable to the investors and to the conservationists who are trying to hold the "birth right of the people" for use and enjoyment by all, rather than permit the creation of monopolies in hydro-electric power, a factor which now enters into the life of each citizen through light, heat, transportation, and other uses.

Transportation or the Fifth Use of Water. In considering the water resources of the nation and their utilization, the kind of use to which they may be put, which has recently been considered as least essential to human welfare, is that pertaining to navigation,—to the carriage of persons and goods. This use was not always thus regarded as fifth in order; on the contrary, from a legal standpoint commerce and navigation originally had first claims, superior in many instances to those of irrigation or disposal of waste. This arises from the fact that in former times when population was less dense, there was little need of conservation or of safeguarding the waters of the country. At that time, before railways or highways were fully developed, the growth of the nation was largely dependent upon waterways. In the constitution of the United States and in national and state laws provisions were made for

[1] International Engineering Congress, 1915. Volume on Electrical Engineering and Hydro-Electric Development.

guarding the navigation rights, for then waterworks or sewerage systems were practically unknown and the need did not exist for recognizing them in legal enactments.

There has been a revival of interest in transportation matters and in the period of reconstruction or reorganization following the world war it is more generally appreciated than ever before, that inland transportation is vital to modern industry and that every economically possible means of carrying goods and persons should be employed. Among the various methods are the three designated by the National Rivers and Harbors Congress as the "Transportation Trinity," viz., "Road, Rail, River." As stated by them, "The greatest possible prosperity can be assured to our country only through the equal development and the harmonious co-operation of highways, railways and waterways." Such development is dependent upon engineering enterprise and skill. In this connection attention is given to only one of these, namely, inland waterways.

As an aid to these inland waterways, to render them more effective in the transportation of persons and goods, water conservation by storage has been employed, particularly in connection with canals. In a few instances reservoir construction has been urged because of its assumed benefits to the rivers in their use in navigation.

Under the terms of the constitution of the United States, Congress has sole authority over interstate transportation. Because of this condition efforts are made annually to obtain from Congress large appropriations for improvement of rivers and harbors. Each Congressional district under the operation of the so-called "pork barrel" system is supposed to obtain its share of these appropriations. Thus there are many projects proposed, which, in themselves, have little merit other than that they serve to distribute the funds geographically. The effect upon commerce of the proposed expenditure may be slight, as the immediate object is to secure the money and thus momentarily increase the activity of some particular section. This condition has greatly complicated conditions as regards the investigation and ascertaining of the true merits of any project of inland navigation improvements.

Under this system of Congressional appropriations, storage reservoirs have been built, for example, on the headwater of the Mississippi River, presumably for improving navigation farther downstream. The benefit derived from the use of these reservoirs is not notable and the water when turned into the river has raised the level of the navigable portion hardly more than an inch or two. Much larger benefits, however, are derived by the water power mills situated at or near St. Anthony Falls and it is fairly safe to assume that the persons who urged an appropriation for storage reservoirs have been more concerned with the benefit to be derived by the water power than by the transportation interests. The latter, in fact, are practically negligible, as boats have almost ceased to run on the Mississippi River at points where the height of water would be affected by the discharge from the reservoirs.

Artificial channels for navigation, such as the canals which were built and operated so successfully half a century ago, depend largely upon stored water for the upper levels. Where the canals passed over the relatively high ground or divides between the lower valleys, it was necessary to provide water to supply the loss in lockage, especially during the dry summer time. Many large reservoirs were built in New York, Ohio, and other states. When the canals were abandoned in whole or in part, these reservoirs continued to be utilized in various ways, particularly for water power.

New York Canals. The largest and most important of these canals and the one which has continued in use for the longest time is the Erie Canal, the main portion of which extends from Buffalo at the east end of Lake Erie easterly to the vicinity of Albany, N. Y., on the Hudson River, making a through route for water transportation from the Great Lakes to tidewater. In the construction of this canal a number of reservoirs were built and the subject of water conservation by storage was given early consideration. While the reservoirs were designed with reference to supplying the canal with water for navigation purposes, yet in the course of time there grew up almost unnoticed a large number of water power developments and some

of the reservoirs have proved of considerable value in this connection.

Much of the early prosperity of the state of New York and its present growth has been due to the Erie Canal, thus when the time came that the abandonment of this waterway was seriously considered, the people of the state urged perhaps more by sentiment based on past success than on business judgment, were induced to undertake the reconstruction and enlargement into what is known as the Barge Canal, involving an expenditure of over $150,000,000, paid wholly from state funds and without aid from the federal government.

The Erie Canal was started in 1817, the route of waterway having been gone over previously and approved by President Washington. As originally built, it had a depth of four feet and could float a thirty-ton boat. It was opened October 25, 1825, and soon proved to be one of the world's greatest canals. Settlers flocked from the eastern states westward by way of the canal and prosperous towns were established on the Great Lakes and connecting water. The shipping that once went to Philadelphia and other cities was diverted to New York and the latter soon became the commercial center of the American union, due largely to the facilities provided by the Erie Canal. By 1882 it was found that the Erie Canal had earned over and above all its original cost and the expenses of enlargement and maintenance, a total of $42,000,000. At that time it had a depth of seven feet and could float a boat of 240 tons. Its relative usefulness declined rapidly, however, with the building of through railroad lines, so that to maintain its position the friends of the canal urged that it be enlarged into what is termed the Barge Canal.

The Barge Canal consists of four branches, the Erie running lengthwise across the state, the Champlain extending northward along the eastern boundary, the Oswego branching near Syracuse to Lake Ontario, and the Seneca Canal running southward to the large lakes from one of which it takes its name. It follows in part the old canal, but utilizes wherever practicable the rivers and lakes near its route so that at least 30 per cent is on what is known as the land line. The total length is 446 miles,

of which the Erie proper is 339 miles. The minimum depth is 12 feet, width 94 feet in rock cuts, and 125 feet in earth sections.

All of the locks have been reconstructed and built of concrete. They have a length of 328 feet and a width of 45 feet. The lift varies from 6 to 40.5 feet. The most notable are the five at Waterford at the east end, with a combined lift of 169 feet. In order to utilize the Mohawk River in part, movable dams have been built in the form of truss bridges, from which heavy steel gates are raised or lowered to govern the depth of water in the canalized river bed. The boats or barges will be propelled by mechanical means, the towpath formerly used when the boats were hauled by animal power being omitted. ("The New York Barge Canal" by Frank M. Williams, in Clarkson Bulletin, Vol. 8, July, 1916.)

WATER STORAGE FOR CANAL. The greater part of the water supply for the Barge Canal, as for the old Erie Canal, is derived from the Niagara River on the west and from the smaller rivers near the center of the state. For what is known as the Rome summit level, the water has been obtained from reservoirs on the head of Black River and other streams. From the south of the canal supplies have been received from various creeks, some being diverted from the headwater of the adjacent Susquehanna drainage basin. The most notable work for water conservation is the new reservoir about five miles north of Rome, impounding the water of the upper Mohawk River in what is known as the Delta Reservoir. This is formed by a dam 1,100 feet long with a maximum height of 100 feet. The reservoir has an area of 4.5 square miles and a capacity of 63,000 acre-feet.

Another new reservoir is that formed near Hinckley by a dam mainly of earth, 3,700 feet in length, the maximum height of the masonry portion being 82 feet. The area of the reservoir is 4.46 square miles and the capacity 79,000 acre-feet.

These reservoirs serve not only to supply the Barge Canal, but during the unprecedented flood of March, 1913, the Delta Reservoir stored water of the upper Mohawk so that Rome, Utica, and near-by villages experienced no inconvenience from

the flood conditions. (Barge Canal Bulletin, Vol. 6, page 228, and Vol. 7, page 111.)

With the exception of the reconstructed Erie Canal, there has been nearly complete abandonment of artificial waterways of this character, so that it may be said that at the present time water conservation for purposes of navigation is largely negligible.[1] Nevertheless there are a number of projects which are being discussed from time to time and the effect of construction of reservoirs upon navigation is still a live issue. For example, in the case of the Sacramento River in California. This stream is in theory at least navigable and at favorable seasons of the year a few small boats ply on its water, thus giving an argument for federal control of the stream. The waters, however, have far more value to the state if used for irrigation. It has been proposed to store the floods in reservoirs which may be constructed along the upper reaches of the stream or near the headwater. By the building of these reservoirs the regimen of the river will be greatly altered and it may be found desirable to hold back the entire flow of the river during certain parts of the year. On the other hand, it is urged that the reservoir, if constructed, should be so utilized as to keep a steady flow in the stream. The latter proposition is of doubtful practicability, but it is obvious that from sentimental, if not from more substantial reasons, the question of navigation must be carefully considered when the storage of water on this or other rivers similarly situated is being discussed.

[1] For more complete discussion see:

Harts, Col. W. W., "Rivers and Railways in U. S.," *Proc. Amer. Soc. C. E.*, January, 1915, Trans., Vol. 79, p. 919.

Moulton, H. G., "Waterways vs. Railways," Cambridge, Mass., 1914, 468 pages. (Discusses Lakes to Gulf Ship Canal, "Fourteen Feet through the Valley," and "Eight Feet from Lake to Gulf.")

Plate XVIII. A.
Furrow irrigation, Yakima Project, Washington.

Plate XVIII. B.
Farm lands destroyed by floods; banks of New River near Imperial, California.

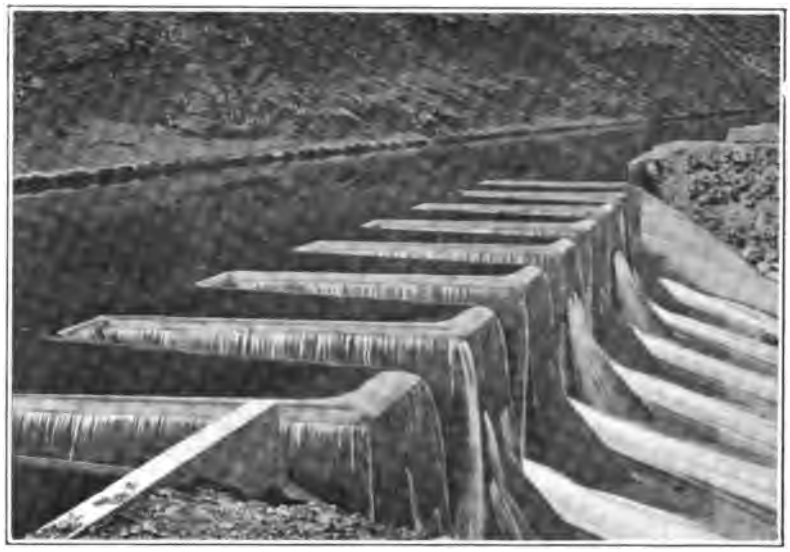


Plate XVIII. C.
Increased length of spillway produced by rectangular bays, Klamath Project, Oregon.

Plate XVIII. D.
River gates in Minidoka Dam, Idaho.

CHAPTER XVII

RIVER REGULATION

COMPREHENSIVE PROJECTS. All the varied uses of water included under the heading previously given, are affected more or less directly by the behavior of the natural streams. In nearly every instance the benefits to mankind are dependent to a certain extent upon a systematic regulation, quantity and quality, of the flowing water, a smoothing out of the inequalities between the extremes of flood and drought. It would, therefore, seem to be the natural course, and the one which will produce the largest benefits to the greatest number, if every river should be studied and treated as a whole, beginning with its headwaters and taking up each natural condition and its relation to the immediate and future needs of the people of the country. This idea, while by no means novel, was most definitely urged by the late Francis G. Newlands of Nevada, whose name is connected with the Reclamation Act, under the terms of which the principal reservoirs of the arid west have been constructed.

Senator Newlands introduced various bills in Congress and persistently brought to public attention the necessity of treating each river system as a unit, studying the forests and cultural conditions from the mountain sources down to the mouth of the stream, ascertaining the most advantageous reservoir sites, providing for the maintenance of purity of water, preventing soil erosion, clearing the channel, utilizing water for irrigation where needed, draining the wet lands, providing for domestic and municipal supply and adjusting the claims for water power, all such work being undertaken with reference to natural conditions rather than being limited by political or other artificial boundaries.

In opposition to this broad conception are the views of individuals and communities who are concerned more directly with

the conditions immediately confronting them. They sincerely believe that while a broad plan may ultimately be desirable, yet for results to be obtained in the near future, they should concentrate their energies upon the immediate local interests and proceed to the building of the levees or to the construction of other works which are obviously needed without delaying to ascertain or discuss the larger matters involved. The advocates of either alternative have many strong arguments to present, these being, on the one hand, for broad research and a constructive policy based on the largest good to the greatest number; on the other, they urge the immediate practical benefits to be derived from concentrated efforts on the things immediately needed. To the student of the whole subject, however, and to the statesman who looks to the future as well as to the present, the conception presented by Senator Newlands is peculiarly attractive and must ultimately be followed if the people of the country as a whole are to enjoy the full use of the natural resources.

The legislation urged by Senator Newlands and finally embodied in a law a short time before his death, forms Sec. 18 of the Act of August 8, 1917 (Public. No. 37—65th Congress). It provides for a Waterways Commission of seven members to bring into coördination and coöperation the engineering, scientific, and constructive services, bureaus, boards, and commissions of the governmental departments of the United States that relate to study, development, or control of waterways and water resources or to the development and regulation of interstate and foreign commerce, with a view to uniting such services in investigating, with respect to all watersheds, questions relating to the development, improvement, regulation, and control of navigation as a part of interstate and foreign commerce, including the related questions of irrigation, drainage, forestry, arid and swamp land reclamation, clarification of streams, regulation of flow, control of floods, utilization of water power, prevention of soil erosion and waste, storage, and conservation of water for agricultural, industrial, municipal, and domestic uses, coöperation of railways and waterways and promotion of terminal and transfer facilities.

The commission is to report to Congress a comprehensive plan for the development of the water resources of the United States for the purposes of navigation and for every useful purpose and to formulate recommendations for coöperation between the United States and the several states, municipalities, communities, corporations and individuals within the powers of each, with a view to assigning to the United States such portion of the proposed development, regulation and control as may be undertaken by the United States, and to the states, municipalities, corporations or individuals such portions as belong to their respective interests.

This commission was not appointed owing to conditions growing out of the war, but it is only a question of time when all these matters must be fully considered. Because of the long delay which may be involved in fully ascertaining the facts and diffusing this information, it is incumbent upon those in a position to do so, to urge the early and comprehensive study of each and every river in the country and the preparation of plans of water conservation such that development may proceed in detail without one scheme interfering with another which may ultimately prove to be more important.

The most apparent need for a broad study of this kind is brought about by the demands for flood prevention and protection and for the correlative demand for more water during times of drought.

Each decade is seeing larger and larger destruction wrought by floods and greater indirect losses through drought. The intensity of floods and duration of droughts are being increased by various human agencies, and more than this, the opportunities for damage are becoming greater. The preventable losses amount not merely to millions, but to tens of millions of dollars. The time is approaching when there will be an appreciation of the fact that by wise foresight and by the expenditure of a portion of this amount, many of the more serious of these losses may be prevented.

While all will admit that a broad study of the subject such as is authorized by the Act of August 8, 1917, should and must ultimately be made and that large expenditures are needed for

conservation, yet action is delayed principally by the question, "Who will pay the bills?" The losses from the lack of prevision fall directly on a relatively small part of the population, although indirectly they are widely distributed. The easy way is to urge that the federal government initiate action and pay for the works, but experience has shown that while this may be accomplished, yet a fairer way and one which in the end will probably produce the largest results is to apportion the ultimate cost in such a way that the nation, the state, the community, and the particular interest involved, will each pay its share. Any scheme of this kind properly worked out has the advantage that it eliminates many of the worst features of "pork barrel" bills in that the incentive of obtaining something for nothing is largely removed. If every local interest, municipality or state, is willing to pay its fair share of the cost, it will be far less insistent upon urging schemes of little merit.

Flood Prevention or Protection. In considering what may be done in a large way with reference to relief from floods, it is necessary to have clearly in mind the difference between flood prevention and flood protection. Each of these must be employed under certain conditions. To appreciate these it is necessary to consider the larger questions. Each stream in a state of nature fluctuates in accordance with the rapid changes of weather. It has a more or less regular periodic fluctuation between high and low water, having usually a spring flood due to increased temperature, the melting of snow, and usual rains. The factors which combine to produce floods vary in intensity from year to year; occasionally the combination of extraordinary rains on frozen ground or with rapidly melting snow produces floods of exceptional violence.

Throughout their geological history the streams during such high-water periods have built up flood planes by deposits from the muddy waters. Such lands are of exceptional fertility and their level character has invited settlement. The tendency has been not merely to cultivate these lands but to build manufacturing establishments and towns upon the level surface. In periods of low water or even of ordinary flood there is no difficulty, but at times of high flood, the bridges, factories, and

other buildings along the bank interfere with the free flow. The river of necessity spreads out and endeavors to take possession of its ancient flood ground, with consequent destruction to property or even life. The immediate answer to questions which are presented to the hydraulic engineer by these flood conditions, is to remove from the river channel and the flood plain the obstructions placed there by man and to erect permanent buildings only on higher ground, saving the lowland for such agricultural purposes as will not be seriously injured by the occasional floods and the lowest land for the scientific growth of timber which encourages important aquatic and riparian faunas. This, however, has often become impracticable, and it is necessary to consider other solutions for the many flood problems. In attacking these there are two lines of effort—*first*, flood prevention; *second*, flood protection.

In flood prevention, the remedy is to be sought by careful surveys and examinations on the drainage basin to discover possible reservoir sites and by storing the flood water in suitable basins, enlarging the natural ponds or lakes or making artificial reservoirs where the floods may be restrained for a period of days or weeks, the excess being let out slowly in accordance with the capacity of the channels to receive it. There are not many localities where adequate reservoir capacity has been provided by nature or where dams can be erected creating a reservoir at a cost commensurate with the immediate benefits. Investigations have been made, however, on the headwaters of many flood streams and it is evident that in the future many reservoirs will be constructed to reduce the flood crest. The further drainage of upland marshes, which serve as natural storage sponges, should be discouraged and the rapid development of water culture of important food plants should be favored.

In flood protection, the object sought is to build near the points of danger large dykes (Pl. IV. C), or walls, shutting off the river from its ancient flood plain, and confining it in a relatively narrow channel. This is the most immediate and direct method of solving the difficulties for any particular locality, but of course does not assist other threatened points as in the case

of reservoirs or similar works built for flood prevention. In fact, the protection of one area may jeopardize another by increasing the flood heights. The combination of flood protection by reservoirs and of flood prevention by dykes offers many interesting problems and is one of the subjects which should be given protracted study as proposed and as already undertaken in a more or less piecemeal way.

Misuse of Streams. It is not alone in quantity of flow, in guarding against flood and drought, that the services of the student and engineer are needed. Even more important in many ways is protection against misuse as pointed out in preceding pages 245 to 256, against thoughtless or careless destruction of many interrelated natural resources, valuable in themselves and for which public funds must be spent, to recover or replace, replenish or maintain. As pointed out by Victor E. Shelford,[1] these resources include:

(a) Animal resources: fish, turtles, frogs, mussels, shellfish, and aquatic birds and mammals.

(b) Plant resources: aquatic vegetation, stream-skirting shrubs and trees, serving as feeding and nesting place of important animals.

(c) Museum resources: preserves for aquatic and riparian faunas for future scientific investigation and possible practical uses.

(d) Recreational resources: bathing, rowing, camping, angling, shooting.

(e) Æsthetic resources.

The preservation of these often conflict with more generally recognized resources, such as water power, water supply, and waste effluent dilution.

The use of streams to bear away sewage and industrial wastes causes pollution and this in turn destroys animal resources, such as fishes and mussels; what was their value and condition before destruction occurred? Pollutions endanger public

[1] The remainder of the chapter is a slight modification of a manuscript by Victor E. Shelford, biologist in charge of Research Laboratories, Illinois Natural History Survey, and assistant professor of Zoölogy, University of Illinois.

health; to what extent is this true, and what is the cost of sickness, incapacitation, or death resulting therefrom? They destroy recreation grounds; what is the value of these to the community and the nation? They may destroy various species of our fresh water fauna; what is the value of these? They may destroy the drinking water of cattle; what is the damage caused by this? Foul odors result; what is the damage of these to the public and property owners near at hand?

Dams may destroy fish and mussels; which is more valuable, these, or the power generated? The draining of marshes drives away game birds; what is their value? What is the museum value of marshes? Is drainage the best way to utilize them? What is their value for aquiculture or for water storage? The task of determining and comparing with each other the benefits and the losses arising from certain customary human interferences with the wild nature of our woods and waters is not by any means a simple one. Even those who have devoted much time and study to such questions have difficulty in comprehending all the complex natural factors and human interests involved even in such an apparently simple matter as the pollution of a stream or the overfishing of a lake or river.

Fishes and Their Value. In the settlement and early development of our republic, fishes were very important. There were shad, salmon, trout, bass, alewives, eels, and many others which "furnished the people a plentiful and healthful supply of food, easily attainable, until the forests could be hewn down, clearings made, crops raised, and cattle could increase and multiply."[1] Shad was the most important. One early writer said of their spring runs in the Delaware and Susquehanna rivers, "They came in such vast multitudes that the still waters seemed filled with eddies, while the shallows were beaten into foam by them in their struggles to reach the spawning grounds." They swarmed every spring from mouth to headwaters of every river from Maine to Florida.[2] They were eaten fresh, and

[1] Wright, Harrison, "The Early Shad Fisheries of the North Branch of the Susquehanna River," Report of United States Commission of Fish and Fisheries, 1881, 619-642.

[2] Meehan, W. E., "The Battle for the Fishes," *Canadian Fisherman*, 1917, 4:275-279.

smoked and salted for winter use. "The testimony shows that the country folk came from fifty miles away to get their winter supply, camping along the river bank, and bringing in payment whatever they had of a marketable nature."[1]

Early in the last century, $200,000 worth of shad were taken annually from the Delaware River alone. They ceased to be abundant about 1850 and by 1880 their value in this river had shrunk to $80,000 per year. This was due to overcatch, to the building of dams, and to pollution. The Atlantic salmon at one time entered all the rivers of New England. Striking apprentices in the early days of our republic demanded less salmon, that it should not be served more than three times per week. Some of our Pacific Coast salmon resources are being reduced in numbers.

Along the Illinois River years ago,[2] the buffalo fish afforded the chief marketable species. These were caught by farmers, fishermen, and others, and shipped by boat, principally to St. Louis, where large quantities of fish were frequently thrown away because the market was overloaded. In 1882, about 250,000 pounds of fish, nearly all buffalo, were taken at one haul of the seine, in Moscow Lake, just below Havana, Ill. In recent years less than 8 per cent of the total fish catch in a year at Havana has consisted of buffalo—the total catch of buffalo in 1912, amounting to only about 94,000 pounds. Recent hatchery experience on the Illinois and Mississippi rivers has indicated that buffalo eggs are unusually sensitive to various unfavorable influences. It is believed by some observers that in its present condition in the spring of the year, the central and lower Illinois (as well as the upper) may not offer the best hatching conditions for this species. The wall-eyed pike and the big pickerel are two other sensitive species that have practically disappeared from the Illinois River in the last 25 years, in spite of repeated planting of millions of fry. This is probably due to pollution.

[1] Wright, Harrison, "The Early Shad Fisheries of the North Branch of the Susquehanna River," Report of United States Commission of Fish and Fisheries, 1881, 619-642.

[2] Information in this paragraph supplied by Mr. R. E. Richardson.

The whitefish of the Great Lakes, which served as bread, meat, and vegetable to early explorers and settlers, was once abundant, but now the number is exceptionally small in comparison. Every stream formerly yielded fish to small boys and to old men anglers. If any of these sources now yielded half their original quantity it would be considered remarkable. Our fish resources have been depleted through neglect, carelessness, and the pollution of waters. Such as are still left are endangered by new projects and new pollutions.

The wastes of manufacturing plants and city sewage have greatly aggravated the depletion,[1] or have completed the destruction previously started, in some cases by heedless or greedy fishermen; but the pollutions are far more serious than the initial injury because they preclude the possibility of easy recovery. The destruction of fishes by industrial wastes has been common throughout the country, especially within the last fifty years. The fishes destroyed include those which occurred in commercial numbers, such as shad, salmon, and whitefish and numerous game fishes, such as perch, black bass, and sunfishes.

The destruction of breeding grounds in the Great Lakes is credited with the depletion of the whitefish supply. In 1871, Milner dredged eggs of the lake trout, together with decaying sawdust. The eggs were attacked by fungus.[2] In 1908, Clark expressed the opinion that through the accumulation of slow decaying woody material, water-logged lumber, and sewage, the chief breeding grounds of the Great Lakes had been destroyed and could not be recovered for a long time. If the warning of Milner thirty-five years earlier had been heeded, they would have been in much better condition than at present.

The destruction still goes on,[3] as is shown by such cases as

[1] Marsh, M. C., "The Effect of Some Industrial Wastes on Fishes," U. S. G. S., Water Supply Paper No. 192, 1907, 337-348.

[2] Clinton, G. P., "Observations and Experiments on Saprolegnia Infesting Fish," Bulletin of United States Fish Commission, 1898, 13: 163-172.

Dean, Bashford, "Recent Experiments in Sturgeon Hatching on the Delaware River," Bulletin of United States Fish Commission, 1893, 13: 335-339.

[3] Ward, H. B., "Report on a Preliminary Study of Streams," 1919, New York State Conservation Commission. (In press.)

the following. In January, 1916, in a small river below Springfield, Ill., a town of 50,000 inhabitants, large numbers of dead fish appeared at breaks in the ice, others in a half intoxicated state were caught through holes in the ice. Three thousand pounds of fish were caught in three days, but could not be eaten because of a bad taste. The case was investigated by the Illinois Water Survey. The death of the fish, according to the report, was due to lack of oxygen and poisoning by stream pollutions, brought about by sluggish flow and heavy ice cover preventing aeration.

Industrial wastes are more serious in their destructive effect than household sewage. Lead and zinc works, tanneries, paper mills, and gas plants turn valuable and extremely toxic or poisonous substances into water. Most of the effluents from the gas works are valuable, and all are toxic.[1] Nearly all industrial wastes in Europe have been made into something useful.[2] Why are they not recovered in America? It will not pay! This is not the full answer. More often manufacturers do not care to spend time and energy in dealing with the matter. Their object is to do the primary thing at hand, collect the profits and get rid of the by-products as easily as possible.

The character of wastes varies with the processes from which they result, and the after treatment. Little is accurately known as to the effects of wastes on fishes and other useful animals such as form food for fish; research is needed. The resistance of animals differs with the season, the age of the individual and other factors. Every life history may be represented as an endless chain made up of links of different strength. The life of the species is determined by the resistance of the weakest link. This probably falls in the young stages,—the egg or the young at hatching; it is not known for the life cycle of a single species of fish. The United States Bureau of Fisheries has distributed, for planting, from one to three billion eggs and

[1] Shelford, V. E., "An Experimental Study of the Effects of Gas Wastes upon Fishes, with Special Reference to Stream Pollution," Bulletin 111, St. Lab. of N. H., 1917, 11:381-412.

[2] Koller, Theodor, "The Utilization of Waste Products" (translated from Second Revised German Edition), 1915, Scott, Greenwood & Sons, London; D. Van Nostrand Co., New York.

young each year for many years past, but no work tending to show the most sensitive period has been done. Accordingly when asked whether this or that will injure fishes, no one can tell. This has tended to make engineers ignore fishes. Why should they consider them when the fish expert cannot tell what consideration is required?

Mussels. Fresh water mussels for making pearl buttons constitute an important resource, but one which is decreasing, due to overcatch and pollution which destroy the fish upon which the mussels depend. Coker[1] said: "In one decade pearl buttons were high in price, used only upon the better clothing and commonly saved when clothing was discarded, while in the most general use were buttons of metal or agate or wood which rusted, broke or warped. In the next decade good pearl buttons, neat and durable, were available to everybody and used upon the widest variety of clothing. A former luxury had become a common necessity." In 1908[2] the value of the mussels taken from the Mississippi and its tributaries was estimated at $686,000.

An indication of the importance of the maintenance of our stream and river faunas is the fact that because of the reduction of the supply of native mussels certain manufacturers in order to operate ordered large quantities of shells from China. Japan seized the shells and had them delivered to Japanese factories on the ground that the products of China belonged to Japan. Because of the depletion of the American supply of fresh water mussels, the federal government a few years ago built an extensive laboratory and ponds for research into the life history of the mussels, with a view to increasing their number. It has been found that the young spend part of their lives as parasites on the bodies of fishes, notably on the more sensitive edible game fishes. Thus where there are no fishes there will be no mussels to make the buttons.

Need of Fishways. In the north branch of the Susquehanna

[1] Coker, R. E., "The Protection of Fresh Water Mussels," Report of the Commissioner of the Fisheries, 1912.

[2] United States Bureau of Census, 1911, "The Fisheries of United States in 1908."

in the state of Pennsylvania "The shad industry was wholly abolished by the erection of dams (early in the last century) and thousands of dollars of capital invested in the business was instantly swept out of existence."[1] "There is no question but that the building of dams to feed the canals put a stop at once to shad fishing." The question has been raised as to whether the loss was not "greater than the benefits derived from the great internal improvements." Such canals have been quite generally abandoned in recent years.

Atkins has described a number of fishways[2] but refers to one in the Susquehanna at Columbia, Penn., as the only successful one for shad. It is constructed on a plan deserving consideration, as it is a mere open sluiceway with its lower end an opening in the dam itself and its sides a little higher than the top of the dam.[3] From the opening in the dam the fishway projected as a great sloping bottom. The length is determined by the height of the dam and the slope of the bottom. If the slope is one foot in thirty-five feet the fishway would extend upstream about thirty-five times the height of the dam. The current down the fishway should not be too swift. Most fishways are too small; the best type of fishway is the stream itself and the aim should be to duplicate stream conditions so far as current is concerned. A cost equaling half the cost of the dam is not too much to spend to accomplish it. Fishways have usually been added to completed dams as a sort of cheap adjunct, usually at the expense of a few hundred dollars. This is often done after the fishes have already been depleted from several years of failure to migrate. The importance of fishways is well illustrated by a quotation from Coker[4] relative to the Mississippi dam at Keokuk, Iowa.

[1] Wright, Harrison, "The Early Shad Fisheries of the North Branch of the Susquehanna River," Report of United States Commission of Fish and Fisheries, 1881, 619-642.

[2] Atkins, C. B., "On Fishways," United States Commission of Fish and Fisheries, Report of Commission for 1872-73, Part II, 591-616, 1873.

[3] Bayer, H. Von, "Fishways," Bulletin of Bureau of Fisheries, 1908, 28: 1043-1057.

[4] Coker, R. E., "Water Power Development in Relation to Fishes and Mussels of the Mississippi," Report of the Commissioner of Fisheries, 1913, appendix, viii, pp. 1-8.

"Investigations carried on by the Bureau during recent years have shown that mussels do not necessarily attach to fish indiscriminately, but that a given species of mussel may make use of only certain species of fish, as the pimple-back mussel seems to be generally restricted in parasitism to certain species of catfishes, and, a more striking instance, the niggerhead mussel restricts itself so far as is known to the river herring, or blue herring. Conditions, therefore, which affect the movements of the river herring and catfish may vitally affect the welfare of these important mussels."

It is not here simply a question as to whether mussels will be transported from below the dam to the waters above. If the river herring is a truly migratory fish, going down the river in the fall and ascending again in the spring and if its course is so checked by the interposition of a dam that comparatively few find the way into the upper river, two results will follow:

(a) The fish will become a rare species in the upper river, and

(b) The future generations of niggerhead mussels will so generally fail of finding attachment to the only suitable fish that successive broods will perish. With the ultimate death or capture of the old mussels, the species will become extinct in that portion of the Mississippi River lying above Keokuk,—that is to say, in practically the entire Mississippi, for the mussel resources of the Mississippi proper (tributaries excluded) are exceedingly limited south of Keokuk.

The usual "custom" in such matters will probably be followed here. There will be no fishway until by waiting we discover that damage has been done and then the fisheries will not be worth the making of one. In 1908[1] the fisheries of the Mississippi and its tributaries in Iowa, Minnesota, northern Illinois, and Wisconsin had a total value of more than $500,000. The value of mussels and pearls alone was almost $100,000. If an annual $600,000 fisheries project is endangered, why could not such a sum reasonably be expended for a suitable fishway?

[1] United States Bureau of Census, 1911, "The Fisheries of United States in 1908."

It is doubtful if any salmon stream should ever be dammed without a fishway costing the full annual value of the fish if necessary. Salmon were extinguished in Connecticut River by a dam built in 1798. This also shut out shad and alewives. The value of the shad fisheries of the Delaware about this time was $200,000 per year. With salmon and alewives included, the Connecticut fisheries should have more than doubled this; an expense of 10 per cent of the annual value of the fisheries could have constructed a fishway quite adequate for all the fishes. The very large one in the Susquehanna built in 1873 cost only $11,053.[1] It probably paid to build this dam in 1798, but whom did it pay? Certainly not starving Europe in 1918.

In general fisheries men have not approached the question of fishways with bold adequate projects and river engineers have taken little or no notice of either fishes or fishways. In 1872 Professor Baird[2] said of the cod fisheries: "Formerly the waters abounded in this fish especially in the vicinity of the large rivers. The tidal streams were choked up with the alewives, shad and salmon. The erection of impassable dams across the streams, by preventing the ascent to their spawning grounds, produced almost the extermination of their numbers. The reduction in the cod and other fishes so as to become practically a failure is due to the decrease off our coast, in the quantity of alewives; and secondarily of shad and salmon, more than any other cause. Attention of the legislatures of the New England States has been called to this fact. However, the lumbering interests in New Hampshire and Massachusetts are so powerful as to render it extremely difficult to carry out any measures which in any way interfere with their convenience or profits, and notwithstanding the construction of fishways through dams, these have either been neglected altogether or are of such a character as not to answer their purpose."

Frogs and Turtles. Oneida Lake (N. Y.), which covers

[1] Atkins, C. G., "On Fishways," United States Commission of Fish and Fisheries, Report of Commission for 1872-73, Part II, 591-616, 1873.

[2] Baird, S. F., "Conclusions as to the Decrease of Cod Fisheries on the New England Coast," United States Commission of Fish and Fisheries, Report of Commission for 1872-73, Part II, xi-xiv, 1873.

only 80 square miles, produces $15,000 worth of frogs per year from a narrow margin around the outside.[1] The swamps and marshes near all the large cities produce quantities of these animals but the numbers and values are unknown. The legs are used for food, which constitutes the chief demand, but many are in use in scientific laboratories.

Turtles to the value of $40,000 were taken in the United States in 1908.[2] These figures appear to be quite incomplete or there has been a marked increase as the Louisiana Conservation Commission[3] reports from $100,000 to $110,000 per year for Louisiana alone. Alligator skins valued at $61,000 were taken in the United States in 1908.

Birds. North America possesses about two hundred species of game birds which are associated with watercourses, lakes, swamps, and the seashore.[4] This number includes seventy-four species of edible web-footed fowl. Sixteen of these have been shown to feed upon wild rice, wild celery, and pond weeds.[5] These three plants supply an average of 25 per cent of their food, more than half of which is pond weeds. They are in part dependent upon conditions of water suitable for these plants which grow well in waters not too badly polluted. They are all closely dependent upon water for breeding.

Ducks eat quantities of grasshoppers, locusts, cutworms, and marsh caterpillars. The rails and coot have similar habits and relations. All are useful to the farmer. There are some sixty species of long-legged, slender-billed birds, the so-called shore birds.[6] These devour quantities of mosquitoes, horseflies, etc.,

[1] Adams, C. C., and Hankinson, T. L., "Notes on Oneida Lake Fish and Fisheries" (transactions of American Fisheries Society, XLV, 154, 169), 1916.

[2] United States Bureau of Census, 1909, "The Fisheries of United States in 1908."

[3] Alexander, M. L., "Biennial Report of the Department of Conservation, State of Louisiana, 1916-18."

[4] Forbush, E. H., "Game Birds, Wild Fowl, and Shore Birds," Massachusetts Board of Agriculture, 1912.

[5] McAttee, W. L., "Five Important Duck Foods," Bulletin United States Department of Agriculture No. 58, 1914.

"Eleven Important Duck Foods," l.c. No. 205, 1915.

[6] McAttee, W. L., "Our Vanishing Shorebirds," United States Department of Agriculture, Bureau of Biology, Arv. Circular No. 79.

both adult and larval. Nearly all these birds are very fond of grasshoppers and many feed on weevils, wireworms, leaf beetles, and other pests of the field. Many birds associated with water are useful to agriculture and their destruction ultimately results in heavy losses to the farmer through the increase of insects and other pests. There are also the birds hunted for food and sport.

MAMMALS. The small fur-bearing mammals, closely associated with watercourses—beaver, muskrats, skunks, and mink—are valuable for their furs. Under certain conditions some of them are not desirable; as, for example, muskrats[1] where there are dykes, which they sometimes damage. The skunk[2] is counted as a useful animal and is fond of stream margin thickets. Its bad reputation for taking poultry is unfounded, based largely on rare instances and on the fact that the European polecat from which it gets its name in some localities, is a serious poultry pest. The value of the furs of these animals, except the skunk for which statistics appear to be wanting, in 1908 in the United States exclusive of Alaska was as follows:

Beaver	$ 39,000
Muskrat	136,000
Mink	89,000

WATER MARGINS. The statistics collected in Illinois show that two-thirds[3] of all the birds valuable for eating insects and which for the most part are not included with the shore and aquatic birds, are in some way dependent upon shrubbery, such as that which grows on the margins of watercourses. The bob-white, for example, breeds about thickets and is of especial value to the farmer. It has been predicted that in the Middle West where farmers are inclined to "clean up" the bushes and

[1] Lantz, D. E., "The Muskrat," United States Department of Agriculture, Farmers' Bulletin, l.c. 396, 1910.

[2] Lantz, D. E., "Economic Value of North American Skunks," United States Department of Agriculture, Farmers' Bulletin, l.c. 587, 1914.

[3] Smith, F., "The Relation of Our Shrubs and Trees to Our Wild Birds," 1915, Illinois Arbor and Bird Days, Circular No. 83 (issued by the Superintendent of Public Instruction, Springfield, Ill.), pp. 8-17.

fence corners many of the species dependent upon shrubbery will disappear. The tendency to destroy the thickets, especially on the stream margins, causes an obvious decrease of birds. A good skirting of trees along streams is also of advantage as it is conducive to the presence of fish, because of the fact that many food fishes prefer shade. Moreover, it tends to lower water temperature in summer, a condition also favorable to fishes. The shade greatly increases recreation value. As a rule, the lowest land along streams is not useful for anything but for growing trees and shrubs.

Swamps. Each plan of reconstruction, involving an increase in the amount of land cultivated and designed to provide land for returning soldiers and others, calls for the draining of swamps. The people who advocate this appear to consider the drainage of swamps as an unqualified good. On the other hand, some of the scientists who appreciate the great values in our birds and aquatic resources and who desire to see conditions for scientific study preserved, regard the drainage of certain swamps as an unmitigated evil. One man has proposed the preservation of the entire Everglade swamp region. This may seem absurd, but it is not so preposterous as it appears, if we give full consideration to the value of our North American birds. As destroyers of crop pests, they save millions of dollars in crops every year.

Our southern swamps lie in the direct migration route of many species of birds which are used as food, or which destroy crop pests farther north.[1] This is so important that through gifts and state acquisition, Louisiana has set aside areas of swampy land along the southern coast to serve as way stations for migrating birds and as a breeding place for the native species. Thus swamps have a real value from the standpoint of birds alone; they are not the only animals found in and about marshes, which provide us with necessities, including food, furs, buttons, and other articles. The marshes and watercourses of Louisiana yield upward of $700,000 per year in products from turtles, furbearing animals, and frogs.

[1] Alexander, M. L., "Biennial Report of the Department of Conservation, State of Louisiana, 1916-18."

It is, therefore, reasonable to argue that no swamp in the Gulf States or Georgia should be drained without full consideration of these losses. Experiment stations should be established and at these studies conducted of the means of increasing the productivity of the marshes and of controlling all the present resources.

Upland marshes also have values similar to those of the coastal swamps and an additional and important function. With the clearing off of timber and the draining of such swamps the streams appear to be subject to greater floods and to more extreme low water. The latter conditions in particular are important in connection with the effects of pollution. It is at extreme low stages that the streams are overloaded and that a small amount of pollution overtaxes the self-purification mechanisms, with results almost as disastrous to fishes and similar animals as if the low water occurred throughout the year.

There has been much discussion of the necessity of building dams from which water could be slowly released in dry seasons to maintain flow. It may well be asked, Why then destroy the upland marshes which serve as reservoirs or as great sponges holding water and letting it out gradually? Needham and Lloyd[1] advocate lowering parts of these below permanent water level and putting the soil thus removed on equal areas. The dry land could be used for agriculture and the ponds for water culture. Though the science of aquiculture is as yet in its infancy, yet it appears that water may be made as productive as land.

A part of any large swamp such as the Okefinokee Swamp or any other natural area may be as valuable as the most expensive American museum, one which requires, say, $10,000,000 endowment and $500,000 annual expense. Such swamps are really museums of living things, the value of which at any time may become infinitely great in the solution of important scientific problems which involve living animals. Each year animals and plants find new uses and new values; no one would have

[1] Needham, J. G., and Lloyd, J. T., "Life of the Inland Waters," Ithaca, 1916.

thought white rats, guinea pigs, and common mice worth saving a century ago. If the question of sacrificing all these for a little additional land to cultivate had been raised it would have received but one answer, there would be none of these animals now. Yet by far the greater part of our laws of immunity from disease, heredity of cancer, as well as of heredity in general have been or are still being worked out on them. The investment in equipment and salaries for such investigation amounts to millions of dollars every year. Preserves of our native flora and fauna are more important than museums of dead animals. To quote a recent writer on water culture: "We urge that water areas, adequate to our future needs for study and experiment be set apart and forever kept free from the depredations of the exploiter and of the engineer."[1]

Aquatic Plants. These are not without value; in aboriginal times a number of rushes of different sorts were used for making coarse mats and other suitable articles. In recent years the leaves of the narrow leaved cat-tail have been employed in paper making and in cooperage. In the latter industry the leaves are placed between the staves of the barrels, where they swell when wet and render the joints water tight.

Water plants, notably wild rice, supplied food to the American Indians. This is obtainable at the present time in our own markets in limited quantity and at fancy prices. Hedrick,[2] who has advocated the increase of food supply by multiplying the variety of crops, has stated the uses of several aquatic plants: "In China and Japan the cormbs or tubers of a species of *Sagittaria* (arrow head) are commonly sold for food. There are several American species, one of which at least was used wherever found by the Indians, and under the name arrow head, swan potato and swamp potato has given welcome sustenance to pioneers. Our native lotus, a species of *Nelumbo*, was much prized by the aborigines, seeds, roots, and stalks being eaten. *Sagittaria* and *Nelumbo* furnish starting points for

[1] Needham, J. G., and Lloyd, J. T., "Life of the Inland Waters," Ithaca, 1916.

[2] Hedrick, U. P., "Multiplying Crops as a Means of Increasing the Future Food Supply," *Science*, 40: 611-620.

valuable food plants for countless numbers of acres of water-covered marshes when the need to utilize these now waste places becomes pressing." Research on the cultivation of these should have been started long ago.

Brackish Waters. The fringing seacoast marshes have their uses and before any large areas of brackish or salt marsh are reclaimed by dyking, careful investigation of water cultural possibilities should be conducted. The marshes are suitable for the rapidly declining culture of the terrapin, the catch of which for the entire United States in 1908 was valued at $80,000. Methods of culture must be developed by careful study and research, which must begin almost at the foundation.

The low wet areas along the New Jersey coast have been notorious for the mosquito pests. The increase of these in recent years has been attributed to the decrease of shore birds and water fowl which frequent the marshes, as many of these birds feed on the insects. To compensate in part for this loss of bird life and to perfect the control of the mosquitoes, systems of ditches have been provided by which small fishes, the killifishes, are enabled to get at and devour the larvæ and pupæ. During the war of 1917-18, the munition works discharged a mixture of sulphuric and nitric acids into these waters, which repelled the killifishes and largely destroyed, locally at least, the effects of the ditching work.

Salt Water Problems. The sea and its shallows are highly productive of human food;[1] the cultivated mussel beds of Conway produce 8,600 pounds of flesh per acre, while the productivity of land in beef is about one-ninth of this. The dry mussel flesh is about six-tenths of the dry organic matter produced in grain from the same area of land. Investigation of the possibilities of food culture of the sea should be greatly extended. There are many marine animals not ordinarily eaten which are excellent food, and efforts to extend the number and variety of these on our bills of fare should continue.

The pollution of the sea is quite extensive near our populous areas. The most widely known of these destructive effects is

[1] Johnstone, J., "Conditions of Life in the Sea," Cambridge, 1908.

the contamination of shellfish beds and bathing beaches with typhoid. To prevent this, Winslow and Mohlman[1] have proposed the sterilization of the New Haven sewage. In commenting on the adverse report on the adoption of the plan for treatment of Boston sewage, they say that such calculations fail to put a value on sterile media for bathing beaches and oyster beds.

Such a sterilizing process should render possible the recovery of the valuable substances contained in sewage, and at the same time increase the probabilities of the return of marine fishes and shellfish to the vicinity of large cities and towns where now the raw sewage prevents. It is to be hoped that those who see only the profits to be gained from the sale of recovered products may be persuaded to advocate the introduction of proper processes wherever practicable on the ground not only of the abatement of nuisance and benefits to public health, but also of the probable benefits to fisheries.

There are notable gains to the public to be had in the removal of typhoid danger in sea products, the increase of area usable for shellfish and the lessening of the liability of reducing the breeding grounds of fishes and of hindering their onshore runs. The history of the herring industry is interesting in this connection. Numerous breeding grounds, some of them near prosperous cities, have been deserted and as a result the population of these has diminished. Experiments have shown that herring avoid slight increases in acidity and also water slightly deficient in oxygen as may result from sewage. It is not known whether or not these pollutions caused herring to avoid their usual spawning places, but it is true that such conditions are not favorable to runs of herring. One fact stands out clearly, namely, that many species of marine animals are much more sensitive than fresh water ones. This is in opposition to the fallacy that the sea is so large that sewage and other pollutions can have little effect.

Coöperative Research. From lack of knowledge or through carelessness there has resulted continually recurring destruction of various natural agencies, each working in part toward

[1] Winslow, C.-E. A., and Mohlman, F. W., "Acid Treatment of Sewage," *Municipal Journal*, 1918, 45: 280-282, 297-299, 321-322.

the good of mankind. There has been study of some of these agencies and resources, but the results obtained by private organizations or by individual effort are scattered. The work of our governmental bureaus has often fallen into ruts which have cramped the individual initiative of the investigators. In our present system, as pointed out by Senator Newlands, page 270, the bureaus are usually separate and are often ignorant of the work of each other or are competing usually in ways not based on the logical requirements of the problems to be solved. The complete organization as proposed by the Act of August 8, 1917, should be such that a complete force of investigators can be put to work on a given problem. What should be done with this or that stream, lake or swamp? It is not a problem for engineers alone. There should be a careful study not only of the quantity and quality of the water, but also of the possible related values in fish, game, furs, birds, wood, lumber, and all other products.

Engineers, physicists, chemists, and ecologists (who deal with the fine adjustments of organisms to each other and to conditions) should constitute a coöperative organization which, like an army, undertakes to advance by working together for the general good of humanity. Our laws relative to riparian rights, like those of England, which caused the destruction of the salmon of the Mersey, do not make possible the application to streams and their margins of the best measures for the general good. The laws should be improved and campaigns of education inaugurated. There is need of putting our aquatic resources on a permanent basis. As in the case of other natural resources, there has been too much fish "mining," mussel "mining," i.e., too much of the tendency to take all and go to the next place or the next product, and not enough "farming" of these resources. Why with all our immense rivers should we import mussels from China? Is it not better to work out a basis for a permanent supply from our own waters? Here research is necessary; we know little or nothing about what portion of the individuals of any species can be removed each year and leave the supply permanent and under the best conditions. Opportunities to develop water culture projects in

connection with the building of reservoirs or of undertakings for the reclamation of swamps and the protection of agricultural land from overflow should be given more consideration than in the past.

The ultimate effects of building levees along the rivers in order to confine the floods within restricted channels should also be given thorough research. There has been too great reliance placed on tradition or on text-book assertions as to the behavior of the rivers which have thus been artificially controlled. In particular, attention has been called by Colonel C. McD. Townsend, president of the Mississippi River Commission, to the current fallacies regarding the raising of the beds of certain rivers as a result of levees built along them, shutting off access of flood waters to the ancient flood plains or marsh lands.

He states that those who advocate the theory that levee construction raises the river bed, usually give as an illustration the river Po, and quote a statement which appears to have originated in Prony's "Recherches sur le system hydraulic de l'Italia," adopted by Cuvier in his "Discours sur les revolution de la surface du globe," who added that the floods of the Po exceeded in height the roofs of the houses of Ferrera; and that only by the opening of new river channels in the lowlying lands which were formed by their ancient deposits, could disasters be averted. These statements have been repeated in recent works on geology and geography.

The Italian engineer, Lombardini, refutes these statements; the investigations by French, German and Austrian engineers have resulted in the conclusion that the effect of levees in raising the river bed in no case is more than a few inches in a hundred years, and may be termed a geological effect resulting from the lengthening of the river as it deposits its silt at its mouth. Two reports on the river Po exhaustively discuss the same subject; viz., that in 1905, of a board appointed by the Italian Government, and a paper by G. Fantoli in the Proceedings of the Italian Society for the Progress of Science (Geneva, October, 1912) entitled "Il Po nelle effemeridi di un Secolo."

CHAPTER XVIII

LEGAL AND LEGISLATIVE PROBLEMS

VESTED RIGHTS. In any discussion of the conservation and use of natural resources and especially of water storage, it is necessary to consider not only the physical conditions, but more than this, to have clearly in mind the economic limitations and also the artificial relations established by law. If the entire country was in the state of nature and the engineer could freely pick out the localities where water might best be used or stored and could sweep away all obstacles erected by man, the problem would be relatively simple. He finds, however, that even in a relatively new country innumerable so-called "vested rights" have already attached to the water, and that property lines, as well as state and county boundaries,—drawn without reference to natural conditions,—block his way at every turn. These invisible walls, because of their intangible form, are often more difficult to penetrate than the solid rocks of the mountains, where tunnels may be driven through in the course of a few months. It may require years or may be practically impossible to put through a meritorious project which is obstructed by the vaguely defined rights or limitations set by laws and court decisions. It is the duty of the engineer and of the promoter to know all that he can of these laws so that he may not become entangled in them.

Each of the forty-eight states of the Federal Union has its own system of laws. In some of these a water code has been carefully considered; in others, chaos apparently exists and development of the water resources is effectively blocked because of the existing uncertainty. Taking the states as a whole, however, it may be said that there are two radically different systems in legislation and in court decisions. The first is that of the older states, which for the most part took their legal codes

from England, and which recognize the so-called riparian rights which require that the natural streams be permitted to flow undisturbed in quantity and unchanged in quality. In the other group of states are those of the arid west where the necessity of the people demands that the water be taken from the streams and used more or less completely in the production of crops. Here the so-called doctrine of appropriation has met the common needs of the people better than the riparian rights of the older states based on the common law of England.

Throughout the arid region, as a rule, there is more land than water. In other words, the extent to which the dry but otherwise productive land can be put to use is governed by the care and skill employed in conserving and utilizing the limited amount of water available. The question may thus be asked as to the duties of citizenship with respect to the control of water. Is it a substance whose full ownership may be acquired by an individual and used or wasted according to the desires of that person?

In the case of waters which are abstracted from flowing streams and held in a tank or artificial reservoir, it is usually conceded that the man who thus obtains possession of this definite quantity is the owner and may dispose of the water as he would of other merchandise, but in the case of flowing streams the conditions are different. The stream itself may remain in a definite position throughout all times, but the component parts, the individual particles of water coming from the rainfall on the highlands, are continually being renewed—flowing down the slopes they disappear into the lakes or ocean or go back into the atmosphere. Under these conditions there have arisen at least two theories concerning ownership of the flowing waters. These owe their difference to the contrasting conditions in the country in which the legal theories arose.

Riparian Rights. In humid England and in the nearly equally humid parts of eastern United States, water is usually in excess and its intrinsic value is thus little appreciated. It may be regarded more as a nuisance than an essential element of life. The man who acquired title to a piece of land bordering upon a stream or through which a stream flowed came to be

recognized as having a certain right to the use of the waters of the stream. His land ownership was usually bounded by the center of the stream or by its deepest flowing channel. By the purchase of the land, he acquired the right to use the water and to enjoy certain privileges, these being limited by equivalent rights of the landowners above and below him on the stream. Thus in countries where water was plenty there grew up the conception that the riparian owner could utilize the water so long as he did not interfere with the quantity and with the quality of the water which passed beyond his land to that of other riparian proprietors.

In the case of larger rivers or lakes, the ownership of land covered by water was considered as being in the state and the riparian ownership extended to high-water or low-water mark, but with certain privileges adherent in the fact that the land was bounded by the water surface. The principal causes of controversy under these conditions would be those arising from attempts to develop water power and to build dams, flooding back upon the lands further upstream. In these cases the matter was usually left to private arrangements although in some states flowage rights might be acquired by legal processes.

Appropriation. In the Mediterranean countries of Europe and in the arid western parts of the United States, where, with scarcity of water, most lands and industries, as well as life itself, are intimately connected with the water supply, it is obvious that a different rule must be enforced. The very existence of agriculture depends upon taking away from the streams an ample supply for the production of crops. In the aggregate this removal of water means the complete drying up of the streams and deprivation of lower riparian owners of its use. Obviously it is impossible for each riparian owner to enjoy the use of the water by taking out a portion onto his land and at the same time permit it to flow undiminished in quantity and unchanged in quality. Hence has grown up the doctrine of appropriation. Riparian rights as far as the arid states are concerned have usually been declared to be nonexistent. The men who first took water from a flowing stream and applied it

to beneficial use are thereafter protected in such use in the order of their dates of appropriation and use, or of so-called priority, and to the amount actually utilized.

The ownership of the water in the arid region has usually been declared to be in the people or in some instances in the state. The right to use, as distinguished from ownership, is vested in the various claimants in the sequence in which they first applied this water to beneficial use. Each of the western states has adopted various modifications of these fundamental ideas. In the case of California, there is still some doubt as to the theory which will ultimately be upheld.

It is sufficient to call attention to these two apparently antagonistic views and to the uncertainties which necessarily prevail in many parts of the country because of lack of agreement on fundamentals. It is claimed that more money is being and has been expended in some of the western states in litigation over the right to the use of water than in the building of the necessary works. There is no one matter more essential in the complete development of the resources of an arid region through water conservation by storage than the firm establishment of principles regarding the use of waters and recognition of the fact that this use must be safeguarded in the interest of all the people.

Political Relations. A right social and mental attitude on the part of the public is necessary for success in water conservation and use. While in the past the engineers have concentrated efforts largely on the physical conditions, there is a rapidly growing appreciation of the fact that these leaders must take into account wider forces and must adapt their plans not merely to public needs but to the probabilities of these needs being understood and appreciated. The public directly or indirectly pays for work of this kind and is supposed to get the benefit. Failure to obtain such benefit or to carry out the plans of the engineer to their full completion usually results from ignorance on the part of the public, such ignorance as may be removed, if at all, by the proper use of the larger knowledge possessed by the engineer and his associates. This fact that the political, as well as the physical conditions, must be

given full study by the engineer, too often has been overlooked. In fact, many a good engineer has rather prided himself upon the fact that he has given no thought to the political or social relations of the work. As a consequence many a practicable and desirable scheme of conservation has been wrecked soon after its conception.

It is generally understood that it is the duty of the engineer to utilize the forces of nature for the benefit of mankind. With the growing complication of modern life the successful engineer must include among these forces those which arise from the human relationship. The storms of sentiment or of prejudice with corresponding decrease in confidence may be as destructive to a well-planned work as is the wind or flood. The engineer in making his plans should take these into account, otherwise he may be swept off his feet at the critical time.

In the United States or in any other form of popular government, all consideration of water conservation by storage must necessarily arise from some public or political organization. From the nature of the case, there can be few, if any, strictly private enterprises; even these may require the exercise of some form of public control of the improvement or of the right of condemnation for public uses. Thus nearly every enterprise involving storage necessitates approval by some public official or commission. In the exercise of its functions also there is probability of coming within the range of state or federal laws governing public utilities.

Interstate Activities. The boundaries of each of the forty-eight states were originally drawn with little or no reference to topography or to the watershed of the principal rivers of the country. Some of the states are limited in part by the center of navigable channels or by the low-water mark of a river; but for the most part the boundaries are supposed to be straight lines drawn from a given point and extending west or north to intersect with some other line. It thus results that there are few rivers of importance which lie wholly within any one state. The principal exception is in the case of Texas, the largest state in the Union, involving nearly one-tenth of the total area of the United States. This has wholly within its

area the Colorado River (of Texas, not the Colorado River of the West) and some smaller streams. In California, also, the Sacramento and San Joaquin lie within the state lines. It would be practicable to create a conservancy district wholly within a state on rivers such as these; but even in such instances, there would be involved some consideration of federal laws in working out a scheme of conservation because of the effect which would be produced on the navigable portion of the stream.

The majority of river conservancy problems thus involve the jurisdiction of two or more states as well as that of the federal government in matters of navigation. Here has been a great obstacle to full hydro-economic development. Usually the heads of a stream where water can best be held are located in mountainous areas and in a different state from the lands or property benefited by the proposed storage. To make any enterprise feasible, there must be laws passed in the two or more states sufficiently uniform in character to permit operation. The difficulty of securing such laws can only be appreciated by persons who have attempted to get two or more state legislatures to act in unison. Whatever one legislature agrees upon the other frequently rejects!

Federal Funds. The largest opportunities for development of water conservation and use, exclusive of operations under the Reclamation Act, are those which flow out of federal legislation for the improvement and maintenance of commerce on the rivers of the United States. Under present conditions, a bill is annually reported to Congress involving an expenditure of $40,000,000 more or less for continuation of the work already authorized, for maintaining the works which have been built, and for making surveys of new projects. The custom has arisen, as previously noted, of preparing the items of the bill in geographic order and thus mentioning practically every congressional district. The bill thus includes not only items for the deepening of harbors and of connecting waters in the Great Lakes where results are essential to commerce, but also brings in innumerable items for expenditures on creeks or little rivers where navigation is generally recognized as being impracticable.

The assumption is made in preparing the bill that every part of the United States should have its share of the expenditure—irrespective of the real needs—under the idea that the members of Congress will not vote funds for the larger works of public importance, but which lie outside of their districts, unless each man receives his share.

This low order of public morals is shown not only in the river and harbor bills, but in public building bills and various appropriations for federal works. The precedent has been so generally established that the average member of Congress regards this as a matter of fact. He does not dare to brave the indignation or ridicule of his colleagues by objecting. His constituents also demand that he get his share and secure an amount in excess of that obtained by his predecessors. It is encouraging, however, to see that the public sentiment, long dormant regarding such matters, is awakening to the need of a true budget system and is responding although slowly to the protests of men who have the courage to denounce the "pork barrel" methods and to expose these to the public gaze. One of the men whose name stands foremost for patriotic devotion to higher ideals is that of former Senator Theodore E. Burton of Ohio, one of the best-informed men concerning water transportation, as he gave a lifetime to the study of this both in the United States and abroad. His courageous attacks have awakened others and he has succeeded at least in calling public attention to the reprehensible conditions.

Senator Burton began his fight against the corrupt methods of river and harbor legislation while he was in the House of Representatives. He continued this in the Senate during his term. In the House of Representatives the work was taken up by James A. Frear of Wisconsin.

"The cohesive power of public plunder" has been frequently commented upon (see the *Engineering News*, Vol. 75, June 8, 1916, page 1098). It is shown that the River and Harbor Bill, which carried appropriations of about $40,000,000, although passed by the Senate was favored by a small majority. The number of senators opposing is indicative of the steady growth of public opinion. Emphasis was placed upon the fact

that the senators who led the fight against the bill are in hearty favor of works where expenditure is justified by actual benefits.

WATERWAYS COMMISSION. While a vigorous fight has been waged in the House of Representatives and Senate against the corrupting features of the river and harbor bills, there have been various attempts made to secure constructive action and to outline a patriotic policy to replace the rule of plunder. President Roosevelt, appreciating the situation and finding that Congress as a whole was unsympathetic in such reforms, appointed on March 14, 1907, a commission to prepare and report a comprehensive plan for the improvement and control of river systems of the United States. He stated that in creating this Commission he was influenced by broad consideration and national policy. "The control of our navigable waterways lies with the federal government and carries with it corresponding responsibilities and obligations."[1] This Commission held many conferences and visited some of the more important navigable rivers. It prepared a preliminary report which was transmitted to Congress by President Roosevelt on February 26, 1908. The President sums up the general findings in the following abstract taken from his letter:

"The report (of the Inland Waterways Commission) rests throughout on the fundamental conception that every waterway should be made to serve the people as largely and in as many different ways as possible. It is poor business to develop a river for navigation in such a way as to prevent its use for power, when by a little foresight it could be made to serve both purposes. We cannot afford needlessly to sacrifice power to irrigation, or irrigation to domestic water supply, when by taking thought we may have all three. Every stream should be used to the utmost. No stream can be so used unless such use is planned for in advance. When such plans are made we shall find that, instead of interfering, one use can often be made to assist another. Each river system, from its headwaters in the forest to its mouth on the coast, is a single unit and should be treated as such. Navigation of the lower reaches of

[1] For chairman of this Commission he designated Senator Burton, and as members, Senators Newlands and Warner, Senator (then Representative) Bankhead, Gen. Alexander Mackenzie, Chief of the Corps of Engineers, United States Army, and Messrs. W J McGee, F. H. Newell, Gifford Pinchot, and Herbert Knox Smith.

a stream cannot be fully developed without the control of floods and low waters by storage and drainage. Navigable channels are directly concerned with the protection of source waters and with soil erosion, which takes the materials for bars and shoals from the richest portions of our farms. The uses of a stream for domestic and municipal water supply, for power, and in many cases for irrigation, must also be taken into full account. . . .

"The various uses of waterways are now dealt with by Bureaus scattered through four Federal Departments. At present, therefore, it is not possible to deal with a river system as a single problem. But the Commission here recommends a policy under which all the commercial and industrial uses of the waterways may be developed at the same time.

"The report justly calls attention to the fact that hitherto our national policy has been one of almost unrestricted disposition and waste of natural resources, and emphasizes the fundamental necessity for conserving these resources upon which our present and future success as a nation primarily rests. Running water is a most valuable natural asset of the people, and there is urgent need for conserving it for navigation, for power, for irrigation, and for domestic and municipal supply.

"Hitherto our national policy of inland waterway development has been largely negative. No single agency has been responsible under the Congress for making the best use of our rivers, or for exercising foresight in their development. In the absence of a comprehensive plan, the only safe policy was one of repression and procrastination. Frequent changes of plan and piecemeal execution of projects have still further hampered improvement. A channel is no deeper than its shallowest reach, and to improve a river short of the point of effective navigability is a sheer waste of all its cost. In spite of large appropriations for their improvement, our rivers are less serviceable for interstate commerce today than they were half a century ago and in spite of the vast increase in our population and commerce they are on the whole less used.

"The first condition of successful development of our waterways is a definite and progressive policy. The second is a concrete general plan, prepared by the best experts available, covering every use to which our streams can be put. We shall not succeed until the responsibility of administering the policy and executing and extending the plan is definitely laid on one man or group of men who can be held accountable. Every portion of the general plan should consider and so far as practicable secure to the people the

use of water for power, irrigation, and domestic supply as well as for navigation. No project should be begun until the funds necessary to complete it promptly are provided, and no plan once under way should be changed except for grave reasons. Work once begun should be prosecuted steadily and vigorously to completion. We must make sure that projects are not undertaken except for sound business reasons, and that the best modern business methods are applied in executing them. The decision to undertake any project should rest on actual need ascertained by investigation and judgment of experts and on its relation to great river systems or to the general plan, and never on mere clamor.

"The improvement of our inland waterways can and should be made to pay for itself so far as practicable from the incidental proceeds from water power and other uses. Navigation should of course be free. But the greatest return will come from the increased commerce, growth, and prosperity of our people. For this we have already waited too long. Adequate funds should be provided, by bond issue, if necessary, and the work should be delayed no longer. The development of our waterways and the conservation of our forests are the two most pressing physical needs of the country. They are interdependent, and they should be met vigorously, together, and at once. The questions of organization, powers, and appropriations are now before the Congress. There is urgent need for prompt and decisive action."

THEODORE ROOSEVELT.

(From Message of President printed in *Preliminary Report of the Inland Waterways Commission,* Senate Doc. No. 325, 60th Congress, 1st Session.)

CONCLUSIONS. From what has been stated in the previous pages, it should be obvious that the development and full use of our water resources is not a local or restricted matter, but concerns more or less directly or indirectly the health and prosperity of nearly every person. It is closely tied up with the existence of life itself in that it furnishes water without which no person can keep alive more than two or three days. It bears upon the raising of cattle used for food and upon the production of crops needed for these animals, and for immediate use by man. It enters into the disposal of sewage and waste and the consequent preservation of health. It concerns food and

raw material from aquatic sources, the preservation of birds as crop protectors. It vitally affects manufacturing and production of power used in lighting, heating, transportation, and innumerable ways. It enters into the broad conceptions of the largest future use of the natural resources of the country, increasing the comfort and prosperity of the nation, reducing loss of life and property in floods and in the discomforts produced by droughts.

Viewed in this large way, we can well conceive why a fund has been established for the purpose of keeping before the people of the country the larger aspects of the case. To the young engineer, enthusiastic, not only to enter upon his profession, but to do something really worth while, the great questions of water conservation offer a strong appeal. There is a breadth and bigness which cannot be overlooked; while the way is long and hard and many discouragements must be met and overcome, yet as shown by the pictures already presented, enough has been done to stimulate and encourage future work. This is especially true when it is borne in mind that the structures already built and the results already obtained are merely samples of the larger and more comprehensive projects which should be outlined and entered upon.

It is impossible in a book of moderate size to more than touch upon some of the important points. A whole library is required, embracing not merely books on hydraulics, on construction and management, but also upon economics and legal relations. This is because, as already stated, the problems are far-reaching and involve not only the application of natural laws but also the modification of man-made laws and court findings. While the obstacles to be overcome are great and all may not be successfully met in this generation, yet there is the constant stimulus in the thought that they are not insurmountable and that the reward is sure to him who has vision, perseverance, and ability.

There is no evading the great question of water conservation. Each year it is presented more strongly to our attention. The hundred million and more people who live in the United States already have need for a larger and better regulated water supply and for protection from floods. At the present rate

of increase, other millions will soon be more urgently demanding larger opportunities for life and comfort. New complications are arising and the sooner the problems are attacked, the easier will be the solution. There is every incentive, therefore, for the young man of the present day to seriously and persistently study these matters and to identify himself with the great forward movement which must necessarily take place along these lines.

END

INDEX

Absorption of water, 76, 80, 91
Acre-feet, 105, 195
Acre-feet storage cost, 151
Activated sludge, 244
Adams, Frank, 227
Alfalfa, 189, 223
Alice, Lake, Nebraska, 158
Alkali and drainage, 237
Alkaline lakes, 176
Alkaline lands, 181
Allegheny River, 97
Alta Pass, North Carolina, 55
Alternative sites for dams, 124
Alvord, John B., 97
Amarinds, 35
American Indians, 35
Annual operation cost, 197
Apache Indians, 35
Appalachian forests, 61, 63
Application of water, 228
Appropriation of water, 294
Aquatic plants, 287
Arid regions, 187
Arizona underflow, 79
Arizona Water Co., 156
Arrowrock Dam, Idaho, 140, 142, 159
Artesian wells, 77, 85, 222
Artillery fire, 51
Ashlar masonry, 137
Atkins, C. B., 280
Atlas of American Agriculture, 62
Atmometer, 69
Austin Dam, Texas, 145
Automatic spillway, 213, 219
Average flow, 112

Baguio, 55
Baird, S. F., 282
Baltimore, Maryland, 54
Barge canal, New York, 266
Bass, F. H., 182
Bates, C. G., 69
Battles causing rain, 50
Beadle, J. B., 233
Bear Lake, Utah, 171
Bedrock, 132
Belle Fourche Project, South Dakota, 134, 167
Bigelow, F. H., 70
Biological science, 85
Birds, value of, 283
Black Hills, 82, 87
Boise Project, Idaho, 122, 159
Borings at dam site, 127
Brackish waters, 288
British engineers, 35, 189
British rainfall organization, 50
Brooks, Charles E., 9, 49
Bruckner, Edward, 58
Burdick, Chas. B., 97
Burton, Theodore E., 298

Cable for stream measurement, 106
Calaveras Dam, California, 135
California underflow, 79
California wells, 89
Canadian waters, 172
Canal banks and protection, 218
Canal lining, 217
Carrying unit, 210, 212
Carson River, Nevada, 162, 163, 175
Casper, Wyoming, 158
Catchment area, 202
Cereals, 235
Chestnut Hill Reservoir, Massachusetts, 72
Chezy formula, 109
Chicago, Burlington & Quincy R. R., 87
Chicago parks, 249
Chicago River, 250
Chicago sewage, 251
China, 34
Chittenden, Hiram N., 64
Clealum, Lake, Washington, 166
Climatic fluctuations, 188

Cloudbursts, 55
Clouds, 41, 60
Cody, Wyoming, 159
Cold Springs Reservoir, Oregon, 122, 168
Collecting unit, 210
Colorado River, 94, 99, 118
Columbia River, 168
Columbus, Ohio, 97
Concrete dams, 138
Congress, U. S., 62
Congressional appropriations, 265
Conservation, 28
Conservation of underground waters, 88
Conservation of water, 262
Constitution of United States, 38, 39
Constitutional provisions, 264
Construction methods, 206
Corbett Tunnel, Wyoming, 159
Core walls, 133
Cost of irrigation, 188
Cost of pumping, 221
Cost of water, 196
Cost per acre-foot, 151, 159
Croton Dam, New York, 138
Current meter, 107
Cusecs, 104
Cylindrical gates, 219

Dam failures, 144
Dam sites, 123
Dams, 130
Darton, N. H., 9, 80, 86
Davis, Arthur P., 9, 150
Dayton, Ohio, 96
Debris problem, 100
Debris transportation, 98
Deer Flat Reservoir, Idaho, 122, 132, 160, 166
Dehydration, 72
Deliveries to reservoir, 174
Delta Reservoir, New York, 267
Deming, New Mexico, 82, 84
Denver, Colorado, 75, 89
Depth of run-off, 112
Dew, 59
Dilution of sewage, 244
Discharge measurements, 107
Distributing unit, 210, 214
Diurnal changes, 111
Diurnal flow, 103
Diversion from river, 192
Diversion unit, 210, 211
Divisions of irrigation project, 210
Domestic use of water, 181
Drainage, 187, 237
Drinking water, 181
Drops in canal, 220
Drought, 95
Dry farmer, 196
Drying, 72
Duchesne River, Utah, 165
Dutch windmill, 178
Duty of water, 194, 232
Dykes, 273

Earth dams, 127, 130
Earth reservoir, 223
East Park Reservoir, California, 148
Economics, 31
Edgemont, South Dakota, 84, 86
Egypt, 34, 118
Electricity for heating, 170
Electric transmission, 259
Elephant Butte Dam, New Mexico, 160
Ellis, Arthur J., 77
El Paso, Texas, 145, 219
Engineering relations, 34
Enlargement of canal, 213
Ensign valves, 142
Epidemics, 244
Erie Canal, New York, 265
Erosion, 97
Euphrates River, 99
Evaporation, 65, 121, 152
Everglades, 285
Excessive rainfall, 55
Expansion of agriculture, 190

Failures of dams, 144
Fairchild, H. L., 40
Fassig, O. L., 54
Federal funds, 297
Fifth use of water, 263
Financing irrigation works, 200
First use of water, 37, 180
Fisheries, 247, 256, 275, 279
Flood conservation, 188
Flood plains, 96

Flood prevention or protection, 96, 272
Flooding, in irrigation, 228
Floods and drought, 95
Florida, 81
Fluctuating river flow, 101, 110
Fluctuations of rain, 56
Flumes, 215
Fog, 41
Food production, 185
Forests, 60, 63
Fort Laramie Canal, Wyoming, 212
Foundations, 125, 127
Fox River, Illinois, 249
Franklin Canal, El Paso, Texas, 219
Frear, James A., 298
Freight charges, 234
Frogs and turtles, 282
Frost, 59
Fulke, W., 49
Furrow irrigation, 229

Gage for rain, 53
Gage for stream flow, 106
Gallon, 105
Garden City, Kansas, 78, 79
Gates for dams, 141
Gates of canals, 219
Gates, turnout, 227
Gatun Lake, Panama, 129, 135
Geography, 45
Geological survey, 188
Geology, 45, 86
George, Lloyd, 7
Gilbert, G. K., 98, 101
Glacier National Park, Montana, 114, 171
Granite Reef Dam, Arizona, 154
Gravels, impervious, 239
Gravels, storage of water in, 175
Graves, H. S., 73
Great basins, 92
Great plains, 82, 177, 222
Great Salt Lake, Utah, 165
Green River, Utah, 165
Grover, Nathan C., 94, 114
Gypsum in earth, 167

Hamilton, Ohio, 96
Hansen, Paul, 245
Harding, S. T., 232
Harts, W. W., 268
Hawaiian Islands, pumping, 222
Hazen, Allen, 182
Heads of water, 227
Health, 35
Height of rain gage, 56
Henry, A. J., 62
Herschel, Clemens, 109
Hoad, W. C., 245
Holden, James A., 235
Horton, A. H., 71
Horton, Robert E., 113
Hoyt, John C., 9, 94, 103, 106
Hudson Bay, 172
Human life, value of, 183
Human needs, 45
Huntington, Ellsworth, 58
Huntley Project, Montana, 220
Hutton, James, 49
Hydraulic dams, 134
Hydraulic giant, 100
Hydraulic grade, 81, 88
Hydraulic mining, 105
Hydro-economics, 30
Hydro-electric power, 224
Hydrography, 41, 43
Hydrology, 41, 43

Illinois River, Illinois, 249, 276
Imperial Valley, California, 118
Inbibition of water, 80
Inch, miner's, 105, 233
Increase of cost, 200
India, 34
Indians, American, 35
Inland waterways, 297
Insurance against flood, 95
Interest losses, 198
Internal expansion, 190
International Joint Commission, 253
International waters, 171
Interstate activities, 296
Interstate Canal, Wyoming-Nebraska, 157, 216
Irrigated area, 192
Irrigation, 187
Irrigation by pumping, 221
Irrigation costs, 188, 192
Isoatmic map, 68

Jackson Lake, Wyoming, 122

James, George Wharton, 150
James River Valley, South Dakota, *222*

Kachess, Lake, Washington, 166
Kansas, windmills, 178
Keechelus, Lake, Washington, 64, 166
Kiln-drying, 74
King, F. H., 79
Kutter formula, 109, 218

Lahontan, Lake, Nevada, 162
Lateral canal, 215, 227
Lee, Charles, 176
Legal and legislative problems, 292
Leighton, Marshall O., 182, 245
Limestone, 80
Lining of canal, 217
Lippincott, J. B., 176
Livingston, B. E., 68
Log of well, 85
Loose rock dams, 136
Los Angeles, California, water supply, 184
Lyman Lectures, 5

Maintenance, 225
Mammals, value of, 284
Manufacturing, 259
Masonry dams, 138
Massachusetts State Board of Health, 253
Materials for dams, 125
Maximum flow, 110
Maxwell, Geo. H., 9
McAdie, Alexander, 59
McGee, W J, 9, 90, 299
Mead, Daniel W., 44
Measurement of evaporation, 69
Measurement of rainfall, 52
Measurement of water, 226
Merriam, John C., 9
Merriman, Mansfield, 109
Mesopotamia, 34
Metcalf and Eddy, 252
Meteorology, 41, 48
Mexican Dam, El Paso, Texas, 145
Mexico, 161
Meyer, Adolph F., 44
Miami, Ohio, floods, 96, 144
Milk River, Montana, 115, 172
Mill, H. R., 50
Mimbres River, New Mexico, 82
Mineral water, 184
Miner's inch, 105, 233
Minidoka Project, Idaho, 100, 135, 169, 218, 261
Minitare, Lake, Nebraska, 158
Mississippi River, 68, 265, 280
Misuse of streams, 274
Mixture of air, 50
Morgan, Arthur E., 97
Moulton, H. G., 268
Mountain storage, 121
Mountains and forests, 60
Movement of water, 40
Mussels, 279

National Research Council, 59
Natural flow, 113
Nebraska, windmill, 178
Necaxa Dam, Mexico, 135
Necessity of water storage, 117
Newell curve, 92
Newell, F. H., 58, 79, 93, 149, 232, 299
New England run-off, 66, 91
Newlands Act, 149, 192
Newlands, Francis G., 9, 149, 269
New York canals, 265
New York forests, 62
Nile, river, 99, 118
North Platte River, 127, 156

Okanogan Project, Washington, 135
Okefinokee Swamp, 286
Oldest inhabitants, 52
Olmstead, Frank H., 176
Operation and maintenance, 225
Operation cost, 197
Orchard fruits, 235
Ordinary flow, 112
Orland Project, California, 143
Owens Valley, Nevada, 184
Owl Creek, South Dakota, 134, 167

Palestine, 58
Pathfinder Dam, Wyoming, 127, 156
Paving for dams, 132, 134
Pecos Valley, New Mexico, 83, 89
Pennsylvania forests, 62
Periodic fluctuations of rain, 56
Phelps, E. B., 253